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Vol. 221 **JANUARY, 1936** **No. 1**

MINERAL COMMERCE AND INTERNATIONAL RELATIONS.*

BY

EDWARD SAMPSON, D.Sc.,

Associate Professor of Geology, Princeton University.

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* Presented at a meeting held Thursday, November 9, 1933.

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THE PROBLEM.

Even at a time when the World is suffering from acute troubles involving a great disparity between the ability to produce and the wherewithal to consume, any plans for the future development of a nation must take into account whether the sources of supply, under times of even moderate

pressure, are capable of satisfying the needs of the country in view of its relations with the rest of the World. It is hardly necessary to insist on the vital importance of mineral resources in an age when every person is acquainted with the use of machines and devices which, in turn, are products of more elaborate machines. Agricultural products may have a greater immediate money value but the mineral products play a more far-reaching and enduring part. Attention has recently been called to the fact that, under increasing demands and greatly improved transportation, only the very largest and most favorable deposits are capable of surviving the competitive conditions of international trade. Any country which deliberately uses inferior sources of supply, protected by tariffs or subsidies, will find itself at a disadvantage in a world market. Mineral resources are industrial power. Compare, for example, industrial England and agricultural Argentina. Furthermore, great concentrations of population of an advanced culture are possible only where great sources of energy are available. Industrial supremacy depends, more than on anything else, on a liberal endowment of mineral resources, and it may be well for the American people to bear in mind that our industrial supremacy is the result, not so much of our imagined genius as of an endowment of mineral resources which, so far as our efforts are concerned, is purely fortuitous.

It is hard, even for those in a position to know, to appreciate the amazingly increasing rate at which we have been consuming mineral resources of which there is, so to speak, only one crop.[1] Alarmists have told us that for some essential materials the supply can last but a very short time. Others in high places have said that there is no cause for concern and that industry will conveniently solve every problem of diminished supply by substitution, synthesis, or in some vague way. The truth is between these extremes, and important modifications of our present sources of supply will certainly come.

The development of the mineral industry has been one of evolution and we should give due credit to the vast amount of research involved. We came out of the Dark Ages with but

[1] An extraordinarily thorough study of trends has been made by Ivan Högbom and published (in English) in the *Proceedings of the Royal Swedish Institute for Engineering Research*, No. 117, 1932.

few mineral resources, and those playing an unimportant part in the life of the people. In use were iron, copper, lead, tin, gold, and silver; and for power men had wood, charcoal, water, a few domestic animals, and in no small measure their own efforts. Lacking machines, to utilize more energy involved acquiring slaves. From those times until the present there have become available for man's use a great number of new substances. The rare substance of one generation has become the commonplace of the next. The following have been added in succession: zinc, coal, aluminum, cement, nickel, manganese, chromium, gypsum, molybdenum, magnesium, helium, and neon. It is hard to imagine what the future will see us using; surely many of the elements which are thought of as rare, possibly silicon, beryllium, columbium, boron, selenium, tellurium, uranium. They can all be had if they are demanded. Figure 1 gives a list of the main minerals and

FIG. 1.

Metals and Minerals.	Non Metals and Minerals.
Aluminum	Asbestos
Antimony	Asphalt
Arsenic	Barite
Bauxite	Cement
Cadmium	Clay
Chromite	Coal
Cobalt	Feldspar
Copper	Fluorspar
Gold	Fullers earth
Iridium	Graphite
Iron	Gravel
Lead	Gypsum
Manganese	Lime
Mercury	Magnesite
Molybdenum	Mica
Nickel	Natural gas
Palladium	Petroleum
Platinum	Phosphate
Radium	Potash
Silver	Pyrite
Tin	Salt
Tungsten	Sand
Vanadium	Soapstone
Zinc	Sulphur
	Talc

Mineral products in international trade.

mineral products which enter into international trade. The length of the list is some measure of the complexity of the problem.

To evaluate the importance of any of the mineral resources of a country it is necessary to have a clear understanding of the way the substance occurs in the ground, and this in turn involves an understanding of the manner in which it is formed. As an illustration of the problems involved a few instances of the geologic occurrence of some of the major mineral resources are given.

HOW MINERAL DEPOSITS OCCUR.

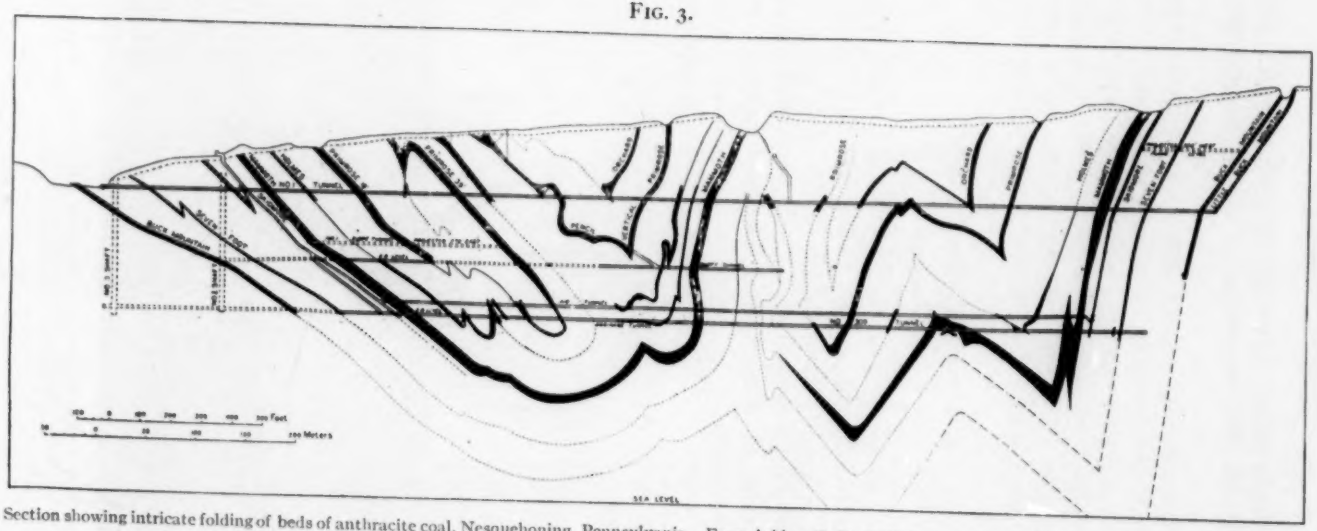
Coal.

Coal is a bedded rock formed by the accumulation of plant remains. Much has happened to a good coal deposit from the time of the original accumulation of the plant remains to the formation of a high rank coal. Peat represents an early stage in the process of alteration. The sedimentary materials,

FIG. 2.

A flat lying deposit of sub-bituminous coal. Pittsburg field Kansas. Large shovel is stripping —feet of overburden. Nearest shovel is mining—feet of coal exposed by stripping.

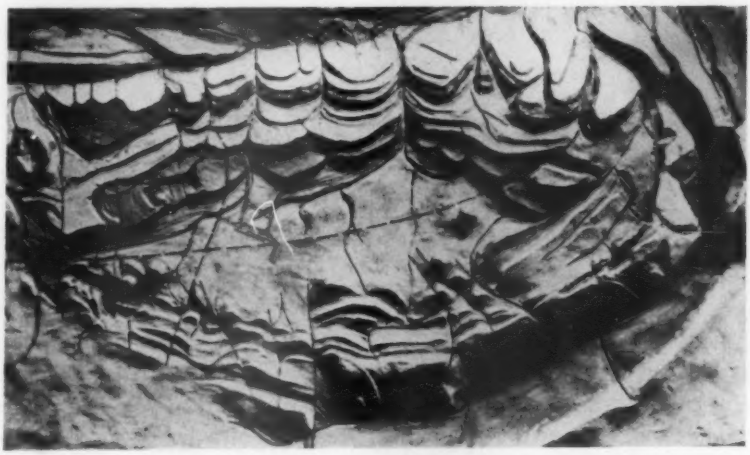
FIG. 3.



Section showing intricate folding of beds of anthracite coal, Nesquehoning, Pennsylvania. From Ashley, G. H., XVI International Geol. Congr. Guidebook 8, Pl. 6, 1932.

sand or mud rocks with which the coal is associated were flat-lying, but all of the higher grades of coal are members of series of sedimentary rocks which have been subjected to mountain building forces. The more the beds in which it lies have been folded and crumpled, the more the coal has been affected. Peat may be changed to lignite, or brown coal, and that in turn to bituminous coal and finally anthracite. It requires, then, a combination of fortuitous events to produce a high rank coal, and the higher the rank, the less likely is this combination to have taken place. A contrast of conditions is shown in Figs. 2 and 3. The nearly flat-lying beds of Kansas yield but a low rank bituminous coal, whereas the highly folded beds of the Appalachian Mountains in northeast Pennsylvania contain the World's greatest deposits of anthracite. A further factor complicates the appraisal of a coal field. All coal used in making steel is now first made into coke. Only a few bituminous coals are suited for this purpose. The property of coking is then dependent upon agencies from without which have brought the coal up to bituminous rank (but not as far as anthracite); and in addition it appears to be dependent upon subtle factors in the original composition of the deposit.

FIG. 4.

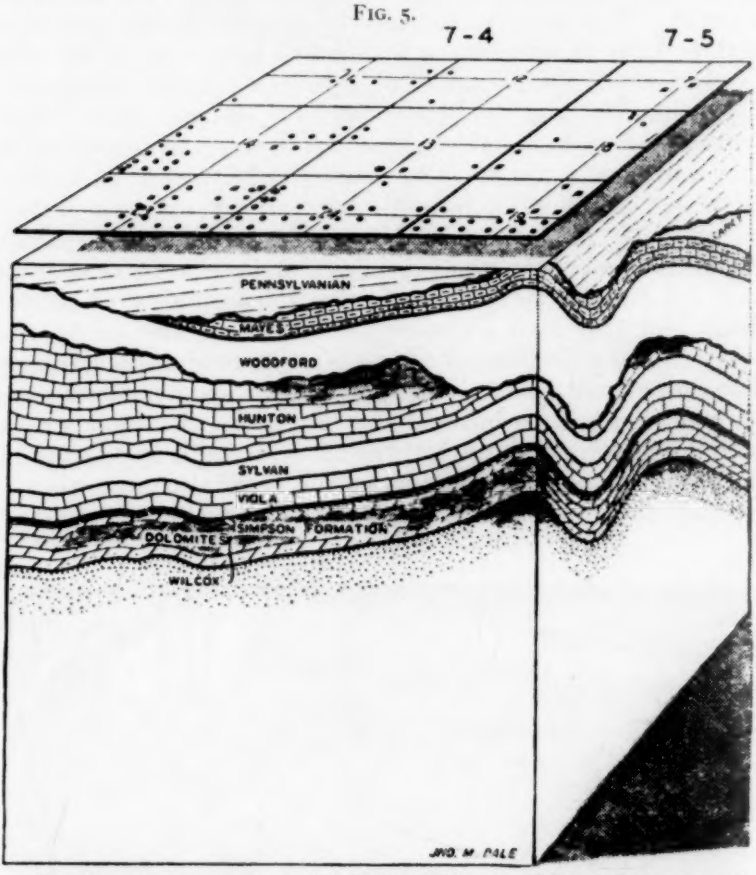


Model of topography, Elk Basin oil field, Wyoming. Shows topographic expression of geologic structure. The dashed lines indicate location of axis of structure and faults. Model made by F. W. Bates and F. N. Spencer, Jr., from their own topographic and geologic survey.

Petroleum.

Petroleum, like coal, is a product of the sedimentary rocks, and the workable deposits are again the result of the action of two entirely independent processes. First, is the accumula-

FIG. 5.



Subsurface geologic structure in Seminole district, Oklahoma. All information secured by the correlation of well records. The surface geology gives no clue to the subsurface producing structures. The plane at top of figure shows land subdivisions and the location of producing oil wells. From A. J. Levorsen, Greater Seminole district, etc., Ann. Assoc. Petroleum Geol., 1929.

tion of the remains of organisms in certain muds on the floors of shallow seas and the greater or less consolidation of these muds to form rocks with the development of liquid hydrocarbons. Second, is the migration of these liquid hydrocar-

bons, petroleum, into certain porous and permeable rocks which act as reservoirs and allow the petroleum to accumulate. This process of accumulation involves a great concentration, for the petroleum of the source beds was present only as minute particles disseminated through the rock, the process of concentration being brought about by moving artesian waters which left their load of oil where some suitable trapping

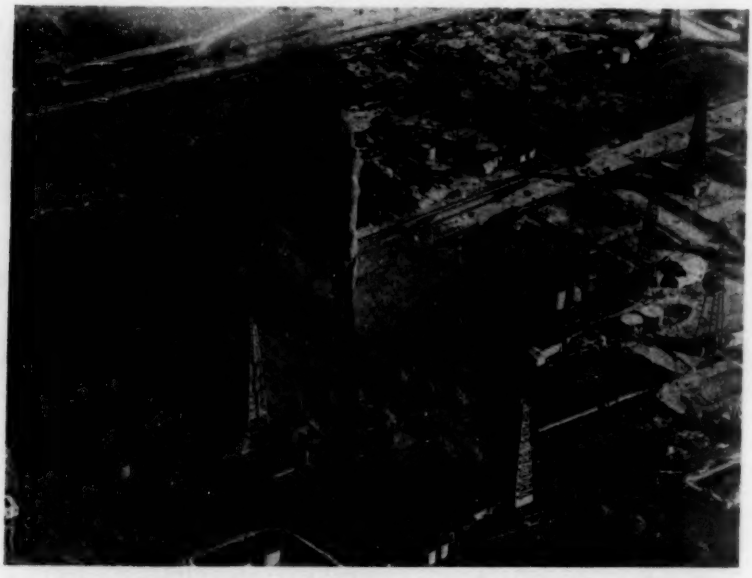
FIG. 6.

Search for oil by geophysical methods. A seismic survey. The truck contains about $20,000 worth of electrical equipment. The wires lead in from geophones which record the results of a small artificial earthquake. Finished seismograms being inspected a few minutes after shot was fired.

structure was available. The search for petroleum is largely the search for suitable reservoir structures. The science of oil finding has passed through a number of stages of which the following may be mentioned: actual seepages of petroleum; reservoir structures whose surface indication was clear (Fig. 4); then came accurate geological mapping of the surface geology thereby revealing structures which are not otherwise apparent; then followed the extensive use of subsurface methods

whereby the cuttings from wells were carefully studied and compared and in this way a picture of the underground geology laboriously built up (Fig. 5); and finally has come the use of geophysical methods by which tests conducted at the surface can be made to reveal much concerning the structure at depth (Fig. 6).

FIG. 7.



Developed oil field with well out of control, Athens, California. Such spectacular occurrences are unusual. The well is throwing gas and mud. Spence Air Photos, Los Angeles.

Iron.

The World's supply of iron comes from many different kinds of sources. Some of the greatest deposits, like those of Lorraine, Alabama, and Newfoundland (Fig. 8), are from sedimentary rocks and are of great continuity. The largest deposits which have been worked, those of the Lake Superior region (Fig. 9), have a dual origin, iron having been first somewhat concentrated in certain peculiar sedimentary beds and these beds then further acted on, probably by weathering agencies in the remote past, to form the workable bodies of iron ore. Again, a combination of independent processes was

FIG. 8.

Surface workings on sedimentary iron ore, Bell Island, Newfoundland. The same beds are mined by underground workings which extend out two miles under the ocean. Photo by Gilbert van Ingen.

FIG. 9.

Iron mine, Mesabi Range, Minnesota. Shows drills on tractor mounts and method of loading ore. Standard gauge trains are run into pits. This is one of the smaller pits on this range.

required, with the probabilities so greatly against such a combination that the Lake Superior district is the only known one of its kind of any importance. Other iron deposits have formed deep within the earth through igneous agencies. Such deposits are fairly common and may be of very high grade but only a few are of sufficient size to be workable under present conditions although, up to fifty years ago when charcoal smelting was still in use, many such small isolated deposits were mined. The great deposits of Swedish Lapland are the most important deposits of this class now being worked.

Copper.

Copper is concentrated into deposits of workable grade and size in many different ways. More extreme processes of concentration are required to form a workable body of copper than for a body of iron ore of equal importance. All the metals of commerce are distributed throughout the common rocks in minute quantities. The average quantities are fairly well known. It may be of interest to record the degree of concentration necessary to produce an ore. The table below indicates that it takes twenty times as much concentration to produce an ore of copper as it does to produce an ore of iron.

Concentration Necessary to Produce Ore.

Metal.	Average Content of Metal in the Ordinary Rocks.	Content of Metal in Ore.	Ratio of Concentration.
Iron	5.1	50	10
Copper	.01	2	200
Zinc	.004	4	1,000
Lead	.002	6	3,000
Silver	.00,000,x	.07	10,000
Gold	.00,000,0x	.001	10,000

In general, copper deposits have formed from emanations from deeply buried masses of molten rock (more correctly magma). These emanations have dropped their load of dissolved metal on reaching positions of different environment. Again a secondary process may have entered in, but in the case of the copper deposits it is a most far-reaching one, namely, the action of rain water that seeps through the upper zone of unsaturated rocks, dissolving copper, which is again

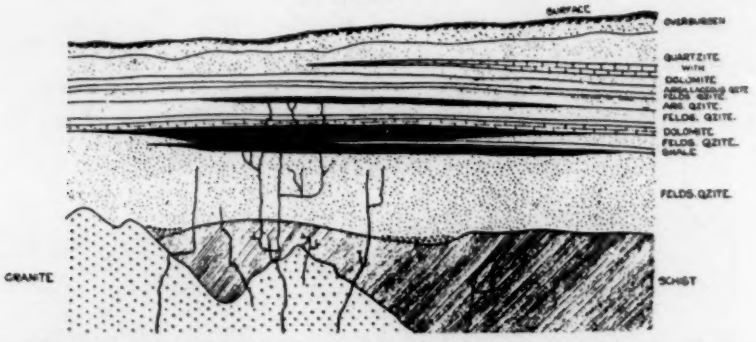
deposited in a zone of secondary enrichment where the descending solution enters a region where the rocks are permanently saturated with relatively stagnant water. This process of enrichment has been the final and vital process in the formation of most of the "porphyry coppers" (Fig. 10).

FIG. 10.

Mining a low grade copper ore at Bingham, Utah. Shows system of breaking and hauling ore and the solution of the problem of disposing of the worthless material which overlies the ore.

Copper also occurs in vein deposits, as at Butte, Montana, which may extend to great depths. There, from "the richest hill on earth" over two billion dollars worth of copper and associated metals have been recovered. Of great interest at the present time is the group of extraordinarily rich copper deposits of Northern Rhodesia and adjacent parts of Belgian Congo. The geological relations are best known in Northern Rhodesia, where the copper occurs in crumpled strata of sandstone. It is thought that the copper has been introduced by solutions which have traveled upward from cooling bodies of molten material which invaded the region at the time the bedded rocks were folded. An indication of the inferred conditions is shown in Fig. 11.

FIG. 11.



Diagrammatic section illustrating supposed manner of origin of ores, Mufulira mine, Northern Rhodesia. Solutions from granite cooling at depth migrated upward in certain sandstone beds. Later the whole series of rocks was strongly crumpled to give the complex structures now found. From plate of Anton Gray, Econ. Geol., vol. 27, p. 336, 1932.

Lead and Zinc.

There is strong and fundamental difference of opinion as to how some of the most important deposits of lead and zinc have been formed. However, it appears that they are deposited from solutions of ultimate igneous origin some of which have traveled so far that it may be difficult to determine what kind of a source they had. The great deposits of Missouri and adjacent regions are of this type. Others in mountainous regions are of more immediate relation to igneous sources. Lead and zinc minerals may form separate ore bodies or they may be intimately associated. Only in recent years has it become possible to separate economically the lead and zinc of certain very large deposits which up to that time were of no value. Most of the World's silver comes from lead-bearing ores.

Gold.

The old miner's saying that "gold is where you find it" recognizes the fact that gold, although very sparingly present, is one of the most widely distributed of the rare elements. Also, gold is found in many different kinds of deposits. The combination of these factors has resulted in no large area of the earth being without gold deposits. This itself certainly contributed to the widespread use of gold as a medium of exchange. Gold has formed from solutions of igneous origin both deep within the earth and rather close to the surface. The deposits which were originally deep-seated were formed

over a much greater vertical range than the originally near-surface deposits. The near-surface deposits have furnished some of the World's greatest bonanzas; and, though they may have played a conspicuous part for a time, they were short-lived. The bonanza camps of early fame in Nevada were of this type. On the other hand the gold camps of

FIG. 12.

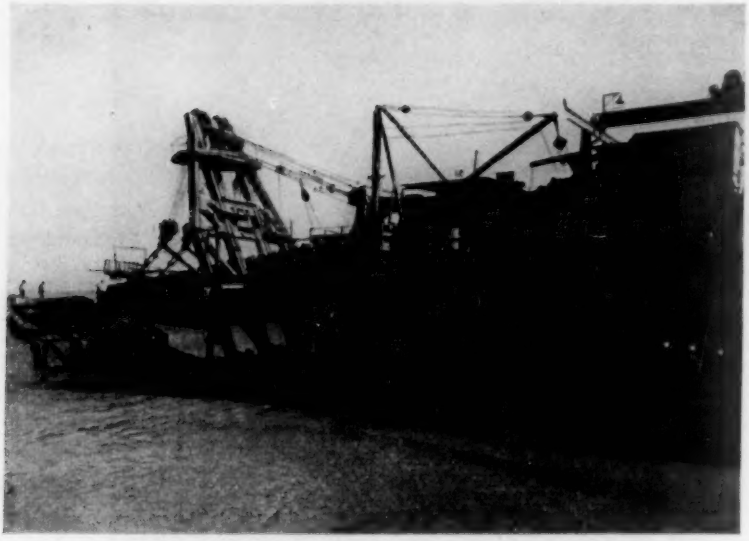
A small placer gold operation, Independence District, Boulder River, Montana. The gold is caught on ripples in the bottom of the sluice box shown.

Ontario and Quebec, being of a much deeper-seated type, hold great promise of a long and productive life. In the placer (alluvial) deposits gold has been collected by the agents of erosion from many sources and concentrated by moving water which has carried away the lighter materials and left the gold behind in certain favored locations (Figs. 12 and 13). Placer

gold deposits are perhaps the easiest to find of all the mineral deposits. In the history of development of any country, the placer gold deposits may be an important factor in its early wealth, as witness Egypt, California, and Australia.

About half the World's gold comes at the present time from a single district of which Johannesburg is the center. The gold is found in ancient conglomerates of extraordinary persistence from which in all nearly six billion dollars worth of

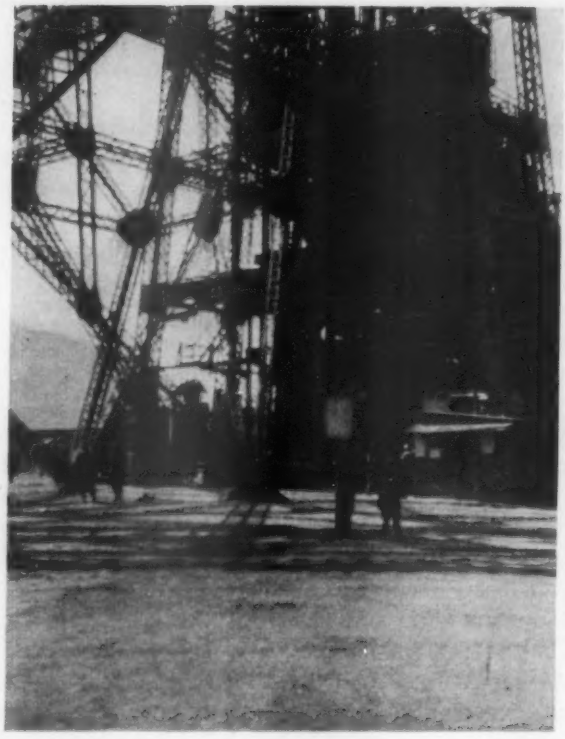
FIG. 13.



Dredging for gold near Sacramento, California. The bucket elevator which forms the digging part of the dredge has been raised to an unusual position and is removing a cut of barren overburden before the pay-gravel is touched. The dredge is floating in a lake of its own digging.

gold has been won. Most of those who have studied the deposit believe that it is an enormous placer deposit, though if this be the case it differs in many features besides size from any other placer deposit known. Recent discoveries have given hope that the field may be greatly extended, a matter of much importance, for in part of the field the deepest mines of the World already penetrate to depths of over 8,000 feet (Fig. 14).

FIG. 14.



Deep mining for gold. Head frame of deepest mine in world. Robinson Deep, Johannesburg.

The Ferro-alloys.

The ferro-alloys are used in the making of steel in a manner likened to the use of yeast in bread. They are of an importance in the industry out of all proportion to their money value. They are essential materials, the supply of which must not be interrupted. The metals of this group include manganese, chromium, nickel, vanadium, tungsten, and molybdenum. To a moderate extent they are interchangeable, but if the highest grades of steel are to be made a liberal supply of ferro-alloys must be had and their use is increasing greatly.

In the case of all these metals a very few deposits supply the World's demands, and most of these deposits are far

removed from the markets. A first class deposit of a ferro-alloy can be worked profitably in almost any part of the World.

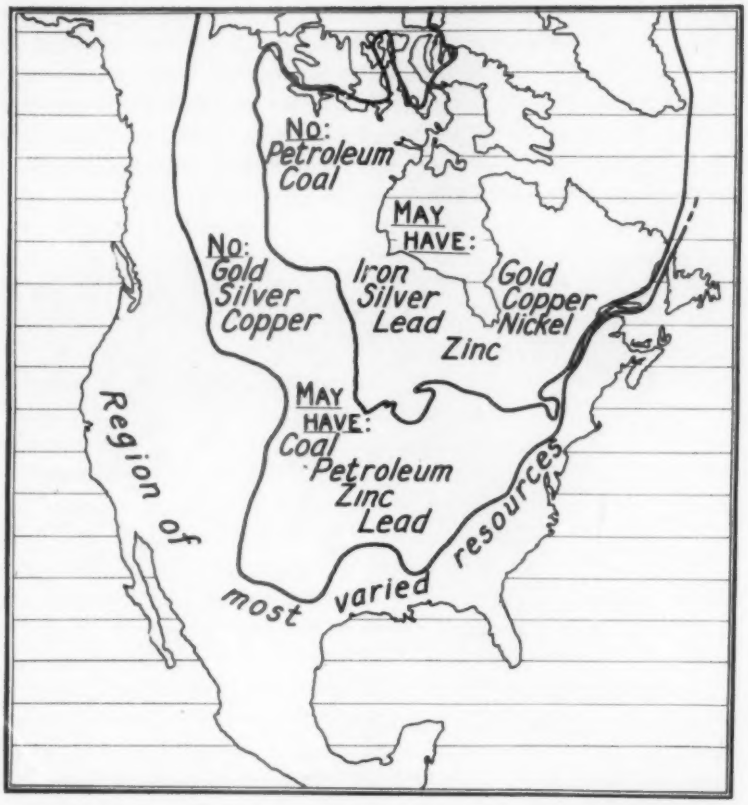
A NATIONAL ACCOUNTING.

Inequality of Distribution.

Mineral resources are most unequally distributed throughout the World. The full extent of this inequality may not be generally realized, although the reasons are obvious enough when they are marshaled together. Mineral deposits are the results of definite geological processes, which in turn are but episodes in the complete history of any region. The fortuitous nature of the processes necessary to produce ore has been emphasized. Only in regions where the proper primary events have taken place is there any chance for the secondary ore-forming agencies to have been effective. With this in mind, the world may be divided into definite regions concerning which we may say with a good deal of assurance that a certain mineral resource may or may not be found. The structure of all the continents is similar in many respects. In each a large nucleus of very ancient rocks after a long and intricate history became a stable area not again yielding to intricate deformation such as produces mountain ranges and permits the intrusion of great quantities of igneous material which may give rise to ores. These great stable areas are known as the shield areas. As time progressed, mountain ranges formed on the margins of the shields by a crowding of material against the shields. The periods of mountain building culminated with igneous intrusion, which in turn cemented the zone of instability and joined it to the shield area. Although the shields showed great stability with respect to compressive forces which formed mountain ranges, they were subjected to mild up-and-down movements and to gentle warpings which permitted the incursions of shallow seas over shield areas. Advances and retreats of "continental" seas took place many times and left deposits of rocks that have covered much of the shield areas. The exposed shield areas are rich in minerals, particularly those that formed at great depth. The covered shield areas contain but few metal deposits, of which the lead and zinc deposits of the Mississippi Valley are the most important, but they do hold important

deposits of petroleum and coal. The fringing mountain ranges with their great variety of rocks are great storehouses of mineral wealth. Figure 15 shows, in a somewhat simplified fashion, the division of the North American continent into these provinces.

FIG. 15.

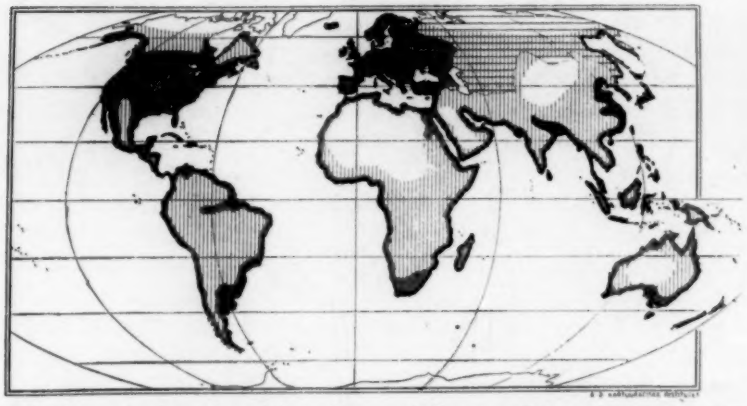


Mineral provinces of North America. The resources found depend on the geological history of the region. The division of this area among many small countries would bring about very unequal and poorly balanced resources.

These broad geologic features are strongly represented in the figures of mineral production. To be sure, countries are in very different stages of development of their mineral wealth and no statistics can properly represent potential production. Nevertheless, this is on the whole a minor factor,

for there are usually sound economic factors working against those regions, even if they contain deposits of known potential importance. If a small country is favorably situated geologically, as for instance Czechoslovakia, it may be largely self-sustaining; on the other hand even a large country, like Argentine (with its only likely mineral region along the Andes and very far removed from markets), may find that its best course may be to make the most of its agriculture and go its way quietly, depending on outside sources for its mineral supply which will come to it mostly in the form of the manufactured articles. The extent to which transportation controls the workability of a mineral resource is well shown by a map of Högbom's which is reproduced as Fig. 16.

FIG. 16.



Sketch-map showing regions of the world economically accessible for exploitation of different minerals. Black: Coal and Iron Ore. Dark shading: Petroleum. Light shading: Copper. Blank: Gold. Soviet Russia has been given a special indication. Map of Ivan Högbom, Proc. Roy. Swedish Inst. Engineering Research, No. 117, 1932.

System of Accounting.

The system of accounting used in this present appraisal of mineral resources is based partly upon fact and partly upon what is purely opinion. However, the two are given separately, and those who may have opinions different from the present writer have the basis for making their own combinations. Figure 17 gives the per cent. of the total World production of each country for each of the mineral commodities which play an important part in World trade. These figures are

based on those published by the League of Nations.[2] The factors of relative importance are assigned arbitrarily. The writer believes that this arbitrary appraisal of the importance is better than that which could be arrived at by considering only the immediate money value of the product. The trading value of a commodity increases according to the degree in which it is essential and to the number of equally good deposits which exist. Under conditions of uninterrupted trade the price and total value of the commodity sold will not measure adequately these factors. The ferro-alloys give us a clear example of this. Also the value of the annual output of new gold is small as compared to the stocks. Economists can do far more in varying the manner that financial structures are built upon the base of gold stocks than the miner can hope to bring about by any likely new finds. The factors selected for "relative importance" represent an attempt to balance these various considerations.

A few words of explanation are perhaps in order with regard to the separate commodities. Coal is surely the most important of the mineral resources and has been given a value accordingly. Natural gas is too much a product of the United States alone to be given a rating, not so much because we are the only country endowed but because conditions have particularly favored its exploitation in this country. Not the least of these has been the freedom from impeding political boundaries. The distance from the Carpathian fields to France is much less than pipe lines in operation in this country. Pig iron is not included in the weighted total because pig iron production is a reflection of the coal resources of a country. On the other hand, both aluminum ore (bauxite) and metal have been included because the production of aluminum metal requires the use of an important natural resource, cheap energy, mostly in the form of water power. Gold has been given a weight which may appear to be low, but this was done because of the smallness of any one year's production of gold in proportion to the permanent stock which

[2] Statistical Yearbook of the League of Nations. League of Nations Economic Intelligence Service, Geneva. For a few commodities or countries the League of Nations figures are not adequate, and to supplement these numerous other sources have been consulted.

FIG. 17.

Group.	Fuels.			Iron.		Non-ferrous Metals.						Precious Metals.		Fertilizers.			Ferro Alloys						Miscellaneous.							Total Score.	Per Cent. of World Total Score.
Relative Importance.	15	10	—	10	—	5	4	4	2	4	4	3	2	2	2	2	2	2	1	2	1	1	¼	¼	2	½	½	½		
Commodity.	Coal.	Petroleum.	Natural Gas.	Iron. Ore.	Iron. Pig.	Copper.	Lead.	Zinc.	Tin.	Bauxite.	Aluminum. Metal.	Gold.	Silver.	Phosphates.	Nitrates.	Potash.	Chromite.	Manganese.	Molybdenum.	Nickel.	Tungsten.	Vanadium.	Magnesite.	Graphite.	Sulphur & Pyrite.	Asbestos.	Platinum.	Diamond.			
NORTH AMERICA																															
Greenland																													—		
Canada	1		1		1	6	9	5			14	10	9		2					88			4	1	1	69	13		429	5.2	
Newfoundland				1			1	1																					18		
United States + Alaska	10	67	95	37	44	46	34	39		17	37	11	23	31	8	2		2	93		5	29	16	4	44	1	5		2766	34.1	
Mexico		3				4	15	10				3	41									1		4					243	3.0	
Central America													1	1															4		
Cuba						1											9												23		
Other West Indies		1																											10		
TOTAL	41	71	96	38	45	57	59	55		17	51	24	74	32	10	2	9	2	93	88	5	30	20	9	45	70	18		3493	43.0	
SOUTH AMERICA																															
Colombia		1																									20		20		
Ecuador																													—		
Peru		1				3	1	1				1	8									36							88	1.1	
Bolivia							1		24				2								10								66		
Chile				1		16							1		30														152	1.9	
Argentina		1																											10		
Uruguay																													—		
Paraguay																													—		
Brazil												1						8										2	20		
French Guiana										10																			—		
Dutch Guiana										10																			40		
British Guiana																												2	41		
Venezuela		10																											100	1.2	
TOTAL		13		1		19	2	1	24	20		2	11		30			8			10	36				20	4		537	6.6	

FIG. 17—*Continued.*

Group.	Fuels.			Iron.		Non-ferrous Metals.						Precious Metals.		Fertilizers.			Ferro Alloys.						Miscellaneous.							Total Score.	Per Cent. of World Total Score.
Relative Importance.	15	10	—	10	—	5	4	4	2	4	4	3	2	2	2	2	2	2	1	2	1	1	¼	¼	2	½	½	½		
Commodity.	Coal.	Petroleum.	Natural Gas.	Iron. (Ore.)	Iron. (Pig.)	Copper.	Lead.	Zinc.	Tin.	Bauxite.	Aluminum. Metal.	Gold.	Silver.	Phosphates	Nitrates.	Potash.	Chromite.	Manganese.	Molybdenum.	Nickel.	Tungsten.	Vanadium.	Magnesite.	Graphite.	Sulphur & Pyrite.	Asbestos.	Platinum.	Diamond.			
ANTARCTICA																														—	
AFRICA																															
Madagascar																								11						3	
Moçambique																														—	
Union of South Africa + (S. W. Af.)	1					1	2		1			53					10					24				7	16	58	273	3.4
Southern Rhodesia												3					42									9			98	1.2
Northern Rhodesia									1													12							16	
Nyassaland, Tanganyika, Kenya, Uganda, Soudan, British Somaliland																														—	
Ethiopia																											2			1	
Italian Somaliland																														—	
Eritrea																														—	
Angola																												4		2	
Belgian Congo						7			1			1																25		53	
Nigeria									6																					12	
Gold Coast												1						12										9		31	
Sierra Leone																														—	
French West and Equatorial Af.																														—	
French Morocco														13																26	
Algeria				1			1	1						6																30	
Tunisia							1							20																44	
Spanish Morocco																														10	
Libia (incl. Tripoli)				1																										—	
Egypt														2				5												14	
TOTAL	1			2		8	4	2	8			58		41			52	17				36		11		16	18	96	613	7.5
EUROPE																															
Portugal																					2				3				8		
Spain	1			3	1	3	7	3					1			1					1				25				155	1.9	

FIG. 17—*Continued.*

Group.	Fuels.			Iron.		Non-ferrous Metals.						Precious Metals.		Fertilizers.			Ferro Alloys.						Miscellaneous.						Total Score.	Per Cent. of World Total Score.
Relative Importance.	15	10	—	10	—	5	4	4	2	4	4	3	2	2	2	2	2	2	1	2	1	1	¼	¼	2	½	½	¼		
Commodity.	Coal.	Petroleum.	Natural Gas.	Ore.	Iron Pig.	Copper.	Lead.	Zinc.	Tin.	Bauxite.	Aluminium. Metal.	Gold.	Silver.	Phosphates.	Nitrates.	Potash.	Chromite.	Manganese.	Molybdenum	Nickel.	Tungsten.	Vanadium.	Magnesite.	Graphite.	Sulphur & Pyrite.	Asbestos.	Platinum.	Diamond.		
United Kingdom	19	..	..	7	8	..	1	..	2	..	3	..	..	2	8	..	..	..	..	..	..	..	..	..	..	..	..	..	395	4.9
France	4	..	..	25	11	..	1	1	..	30	11	..	..	6	4	18	..	..	..	..	..	..	..	..	2	..	..	..	542	6.7
Saar	1	..	..	..	2	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	17	
Luxemburg	..	..	..	4	3	..	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	44	
Belgium	2	..	..	..	4	..	..	..	..	..	..	..	..	3	2	..	..	..	..	..	..	..	..	..	..	..	..	..	40	
Netherlands	1	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	17	
Germany	15	..	..	3	13	1	3	7	..	..	12	..	2	5	3	78	..	..	..	..	..	..	..	1	3	..	..	..	596	7.3
Switzerland	..	..	..	..	..	..	..	..	..	..	8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	32	
Italy	..	..	..	..	1	..	2	5	..	9	3	..	..	..	2	..	..	..	..	..	..	..	2	..	11	1	..	..	103	1.3
Greece	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4	..	..	1	..	..	8	..	1	..	..	..	14	
Cyprus	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	..	..	7	
Albania	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	—	
Bulgaria	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	—	
Roumania	..	2	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	22	
Yugoslavia	..	..	..	..	..	1	1	..	..	5	..	..	..	..	..	..	7	..	..	..	..	..	1	..	..	..	..	..	43	
Hungary	..	..	..	..	..	..	..	..	..	18	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	74	
Austria	..	..	..	1	..	..	1	..	..	..	1	..	..	..	..	..	..	1	..	..	..	..	11	17	..	..	..	..	35	
Czechoslovakia	2	..	..	1	2	..	..	..	..	..	..	..	..	..	1	..	..	3	..	..	..	..	..	9	16	..	..	..	..	54	
Poland	3	..	1	..	1	..	1	6	..	..	..	..	..	..	2	2	..	..	..	..	..	..	..	..	..	..	..	..	81	1.0
East Baltic countries	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	—	
Norway	..	..	..	..	..	1	..	..	..	..	11	..	..	..	2	..	..	..	6	1	..	..	..	..	6	..	..	..	73	
Sweden	..	..	..	6	..	..	..	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	70	
Finland	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	—	
TOTAL	48	2	2	50	46	6	17	24	2	62	49	—	3	19	56	99	11	6	6	2	3	—	61	47	55	4	—	—	2122	29.8
U.S.S.R.	3	7	1	4	4	2	—	1	—	—	—	5	—	1	—	—	8	35	—	—	—	—	12	1	—	9	43	—	302	3.7

FIG. 17—*Continued.*

Group.	Fuels.			Iron.		Non-ferrous Metals.						Precious Metals.		Fertilisers			Ferro Alloys.						Miscellaneous.							Total Score.	Per Cent. of World Total Score.
Relative Importance.	15	10	—	10	—	5	4	4	2	4	4	3	2	2	2	2	2	2	1	2	1	1	¼	¼	2	½	½	½		
Commodity.	Coal.	Petroleum.	Natural Gas.	Ore. / Iron. Pig.		Copper.	Lead.	Zinc.	Tin.	Bauxite. / Aluminium. Metal.		Gold.	Silver.	Phosphates.	Nitrates.	Potash.	Chromite.	Manganese.	Molybdenum.	Nickel.	Tungsten.	Vanadium.	Magnesite.	Graphite.	Sulphur & Pyrite.	Asbestos.	Platinum.	Diamond.			
ASIA																															
Arabian peninsula																													—	—	
Palestine and Trans Jordan																													—	—	
Turkey (incl. T. in Europe)																	2												4		
Syria																													—	—	
Iraq																													—	—	
Persia		3																											30		
Afghanistan																													—	—	
India and Ceylon	2	1		1	1		6	3	1			2	3				8	28		1	9		2	9					186	2.3
Malay States									36									1			3								77		
Netherlands E. Indies		2	1						20			1	1					1											67		
Siam									5																				10		
French Indo China								1				1									1			5					6		
Philippine Islands																													3		
Japan, incl. Chosen and Manchukuo	3			1	2	4		1				3	2		3		1								1				102	1.3
China	1							1	4									1	1		63		2	17		1			98	1.2
TOTAL	6	6	1	2	3	4	6	6	66	—	—	7	6	—	3	—	11	31	1	1	76	—	4	31	1				583	7.2
AUSTRALIA AND OCEANIA																															
Australia (+ New Guinea)	1					1	12	9	1			2	4								2		1				1		123	1.5
New Zealand												1																	3		
New Caledonia																	8			9									34		
Other Oceania														5															—		
British														2															10		
French														1															4		
Japanese														8															2		
TOTAL	1					1	12	9	1			3	4	8			8			9	2		1				1		176	2.2
GRAND TOTAL																													8124		

Table of rating of countries with regard to mineral resources.

is used in international trade. In the important group of the fertilizer minerals the League of Nations figures permit us to make an even comparison between the natural and synthetic products. In the case of phosphates this is phosphate rock, guano, and Thomas process (basic Bessemer) slag. In the case of nitrogen this includes natural saltpeter, ammonium nitrate, and calcium cyanamide. In all the assigned weights an attempt has been made to offset the money value of the commodity by the part that it plays in industry, and on this basis the ferro-alloys stand much higher than they would otherwise.

Regional Distribution.

If we examine first production and scoring of the continental areas (Fig. 17), several striking features are apparent. The combined score of Europe and North America is 73 per cent. of the World's total. As Leith has remarked, there has been a great concentration of mineral resources around the North Atlantic, and it may well be maintained that the industrial supremacy of this region is the result of an abundant endowment of mineral resources, and not primarily to racial characteristics. If South America or Africa had been as favorably endowed as North America they would have progressed correspondingly, for they were each settled early and would have attracted industrial populations if their mineral resources had been adequate. A corollary of this statement is the small part that agricultural resources have played in continental development in the last 400 years. The demand for agricultural products must exist first, and if the demand be established, agriculture will respond even in very unfavorable regions.

Another feature brought out clearly by the table is the irregularity of distribution of some minerals, even among areas of continental size. North America is without tin, and no deposit is known in the whole continent which remotely approaches workable proportions. In South America the great scarcity of coal is a most remarkable geologic feature. No country of the continent appears to have any reasonable prospect of developing coal deposits adequate for its own needs, much less that of supplying a neighboring country. Europe has been subjected to the greatest pressure in the

development of its mineral resources and, except where recent technical improvements have affected the situation, as in the deeper search for oil, the resources are as fully developed as present technique will permit. The scarcity of copper, gold, silver, and all the ferro-alloys except manganese, causes wants which can only be supplied by distant sources. As Leith and Bain have shown, Asia is deficient in iron, the only known deposits being of questionable importance at best and so situated that any large production of steel is unlikely. Several careful appraisals of Australia's oil have been made, and the present conclusion is that important production from that continent is extremely unlikely. Africa's deficiency in silver, in spite of producing about half of the World's gold, is a remarkable feature. It would appear that the metals were originally distributed with considerable irregularity with respect to large areas of the earth's crust, and that the geologic histories of whole continental areas were so different that whole continents may never have been subjected to the conditions under which coal or oil might form.

In considering the various tables of production figures and scores it is, of course, well to keep in mind that they must represent the figures for only one selected year. The year here chosen, 1929, was selected because the figures represent capacity production more nearly than any subsequent year. The year also represents one of moderately free interchange of commodities between nations. War conditions would present a very different picture. When cost of production ceases to be a controlling factor, very inferior sources will serve. For instance, this country produced a substantial proportion of its requirements of the important ferro-alloys of the war minerals class, chromite and manganese. Under normal conditions, tariffs which would bring out such a large production would impose too serious a burden on the steel industry. In considering the mineral statistics, it is necessary to go behind the figures to some extent if we are to get the complete picture. Nevertheless, if the figures be regarded as qualitative, rather than exactly quantitative, a very good impression of the standing of each country can be obtained. Let us examine the status of several countries which are playing a conspicuous part in world affairs, namely, Japan,

Italy, France, Germany, British Empire, and the United States (see Figs. 18 and 19).

FIG. 18.

More than 10 Per Cent.		10–5 Per Cent.		5–2 Per Cent.		2–1 Per Cent.	
United States	34.1	(France and possession	8.5)	Great Britain	4.9	Spain	1.9
(British Empire	21.3)	Germany	7.3	U. S. S. R.	3.7	Chile	1.9
		France	6.7	Union South Africa	3.4	Australia	1.5
		Canada	5.2	Mexico	3.0	Japan	1.3
				India and Ceylon	2.3	Italy	1.3
						S. Rhodesia	1.2
						China	1.2
						Venezuela	1.2
						Peru	1.1
						Poland	1.0
Cumulative number of countries	1		4		9		19

Countries supplying major part of world's mineral resources.

Figure 18 shows how few countries hold the control of the mineral resources of the World. The United States is the only country with a rating as high as 10 except for the British Empire as a whole. Only four individual countries rate as high as 5, and these account for 53 per cent. of the World total. In like manner only 9 countries rate as high as 2, and only 18 as high as 1, these 18 countries rating 93 per cent. of the total.

Also it is of particular interest to note in Figs. 17 and 18 the very low standing of some important countries and large regions.

Individual Countries.

Japan. Japan's situation in the year 1929 is summed up by its total score of 1.3 per cent. of the World's total. Though, of course, this figure cannot be taken as exact, it clearly indicates the proper order of magnitude. Indeed, it would seem that in no small measure the shaping of Japanese policy for the last few years has been in recognition of this situation.

The figures of the table (Fig. 19) show a striking shortage of fuels and iron ore. In 1929, 76 per cent. of the coal of Japan, Chosen (Korea), and Manchukuo came from Japan proper, with nearly all of the balance from Manchukuo. Figure 20 shows the location of coal and iron districts in eastern continental Asia. The Japanese coal on the whole is but poorly suited for coke making. The recent acquisition of Manchukuo has changed substantially the situation with regard to

FIG. 19.

	Coal.	Petroleum.	Natural Gas.	Iron. Ore.	Iron. Pig.	Copper.	Lead.	Zinc.	Tin.	Bauxite. Aluminum.	Metal.	Gold.	Silver.	Phosphates.	Nitrates.	Potash.	Chromite.	Manganese.	Molybdenum.	Nickel.	Tungsten.	Vanadium.	Magnesite.	Graphite.	Sulphur + Pyrite.	Asbestos.	Platinum.	Diamond.	Total Score.	Per Cent. of Total World Score.
Canada	1	..	1	..	1	6	9	5	..	..	14	10	9	..	2	..	..	..	..	88	..	..	4	1	1	69	13	..	429	5.2
Newfoundland	..	..	..	1	..	..	1	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	18	
Trinidad	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10	
British Guiana	..	..	..	..	..	..	..	..	..	10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	41	
Union of South Africa	1	..	..	..	..	1	2	..	1	..	..	53	..	..	..	..	10	..	..	..	..	24	..	..	..	7	16	58	273	3.4
Southern Rhodesia	..	..	..	..	..	..	..	..	..	..	..	3	..	..	..	..	42	..	..	..	..	..	..	..	..	9	..	..	98	1.2
Northern Rhodesia	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	12	..	..	..	..	..	..	16	
Nigeria	..	..	..	..	..	..	..	..	6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	12	
Gold Coast	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	12	..	..	..	..	..	..	..	..	..	9	31	
United Kingdom	19	..	..	7	8	..	1	..	2	..	3	..	..	2	8	..	..	..	..	..	..	..	..	..	..	..	..	..	395	4.9
Cyprus	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	..	..	7	
India and Ceylon	2	1	..	1	1	..	6	3	1	..	..	2	3	..	..	..	8	28	..	1	9	..	2	9	..	..	..	..	186	2.3
Malay States	..	..	..	..	..	..	..	..	36	..	..	..	..	..	..	..	..	1	..	..	3	..	..	..	..	..	..	..	77	
Australia	1	..	..	..	..	1	12	9	1	..	..	2	4	..	..	..	..	..	..	..	2	..	1	..	..	..	1	..	123	1.5
New Zealand	..	..	..	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	
British Oceania	..	..	..	..	..	..	..	..	..	..	..	..	..	5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	10	
BRITISH EMPIRE	24	2	1	9	10	8	31	19	47	10	17	72	16	7	10	..	60	41	..	89	14	36	7	10	4	88	30	69	1729	21.3
Madagascar	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	11	..	..	..	..	3	
French Morocco	..	..	..	..	..	..	..	..	..	..	..	..	..	13	..	..	..	..	..	..	..	..	..	..	..	..	..	..	26	
Algeria	..	..	..	1	..	..	1	1	..	..	..	..	..	6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	30	
Tunisia	..	..	..	..	..	..	1	..	..	..	..	..	..	20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	44	
France	4	..	..	25	11	..	1	1	..	30	11	..	..	6	4	18	..	..	..	..	..	..	..	..	2	..	..	..	542	6.7
French Indo China	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	1	..	..	5	..	..	..	..	6	
New Caledonia	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	8	..	..	9	..	..	..	..	..	..	..	..	34	
French Oceania	..	..	..	..	..	..	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	4	
FRANCE and possessions	4	..	..	26	11	..	3	3	..	30	11	..	..	47	4	18	8	..	..	9	1	..	..	16	2	..	..	..	689	8.5
JAPAN and possessions	3	..	..	1	2	4	..	1	..	..	..	3	2	1	3	..	1	..	..	..	..	..	2	..	1	..	..	..	104	1.3
ITALY and possessions	..	..	..	..	1	..	2	5	..	9	3	..	..	..	2	..	..	..	..	..	..	..	..	..	11	1	..	..	103	1.3
GERMANY	15	..	..	3	13	1	3	7	..	..	12	..	2	5	34	78	..	..	..	..	..	..	..	14	3	..	..	..	596	7.3
FRANCE and possessions	4	..	..	25	11	..	1	2	..	30	11	..	..	47	4	18	8	..	..	9	1	..	..	16	2	..	..	..	689	8.5
BRITISH EMPIRE	24	2	1	9	10	8	31	19	47	10	17	72	16	7	10	..	60	41	..	89	14	24	7	10	4	88	30	69	1729	21.3
UNITED STATES and possessions	40	67	95	37	44	46	34	39	..	17	37	12	23	31	8	2	..	2	93	..	5	29	16	4	44	1	5	..	2769	34.1
BRIT. EMP. and U. S.	64	69	96	46	54	54	65	58	47	27	54	84	39	38	18	2	60	43	93	89	19	65	23	14	48	89	35	69	4498	55.3

Summary table of rating of leading nations.

coal, for in the Fushun coal field Japan has secured a supply of subbituminous coal some of which is in extraordinarily thick seams. The quantity readily available is large, the quality fair, some being suitable for coke. However, a major difficulty is the location of the field with respect to Japan's industrial centers. The fullest utilization of this resource will call for the establishment of an industrial center

FIG. 20.

Location of coal and iron districts in eastern continental Asia.

near the coal field. If highly efficient pit mouth power plants were installed, it might be possible effectively to manufacture aluminum and nitrates.

Petroleum seems to be singularly deficient in Japanese territory, though in looking toward the future the possibility of making a "synthetic petroleum," or at least something which will serve much the same purpose, by the hydrogenation of Fushun coal should be clearly kept in mind. At the present

time the price is somewhat high, but it is not unlikely that the next few years will see a distinct increase in petroleum prices, and Japan may well become one of the first countries to use hydrogenation on a large scale.

Iron ore is one of Japan's greatest deficiencies. Leith [3] and Bain [4] show the inadequacy of the deposits of Manchukuo and China, and although one of the best of China's iron deposits, the Hsan Lung field, lies just beyond the seized territory of Manchukuo, even this would not constitute a first class source of supply upon which a real steel industry could be based. Japan proper produced but .08 per cent. of the World's total, with Chosen .21 and Manchukuo .25, a total of .54, which in the table appears as 1 per cent. Pig iron is somewhat higher than iron ore due to imports, and in the past year (1934) Japan's acquisition of scrap iron and steel from overseas has caused much comment.[5]

In the open hearth steel process, scrap material will serve as well as ore, but an iron industry depending almost entirely upon imported scrap is in a precarious position. Japan has no strong steel industry nor any immediate prospect of one.

As to the major non-ferrous metals, copper is the only one whose supplies are even remotely adequate. Bauxite is lacking completely. However, most of the World's aluminum is made from sea-borne bauxite, and if cheap power becomes available reasonably near seaboard, an aluminum industry can be developed. Lead and tin are present only in insignificant

[3] Leith, C. K., "The Mineral Resources of the Far East," *Foreign Affairs*, 4, 433–443, 1926. "The World's Iron Ore Supply"; World Engineering Congress, Tokio, 1929.

[4] Bain, H. F., "Ores and Industry in the Far East"; New York, 1st edition, 1927; 2nd edition, 1933.

[5] An interesting analysis of Japan's policy of buying scrap iron is given by Ray Tucker ("Looking for a Scrap; *Today*," Feb. 16, 1935). The following figures give imports from the United States alone, and Tucker states that the amount of steel acquired from breaking ships (many of which made their last voyage loaded with scrap iron) almost matches the amount of scrap brought from all foreign sources.

U. S. Shipments of Scrap Iron in Long Tons.

	Total Shipments.	To Japan.
1929	516,139	208,260
1934 (11 months)	1,639,193	1,038,440

amounts, and gold and silver supplies are moderate. The fertilizer situation is bad, particularly for a country of dense population. The only "mineral" fertilizers available are synthetic nitrates. Ammonia can only be made as a by-product of coke, so that the output of this is limited by the state of the steel industry. Natural nitrates are lacking, so that sole reliance must be placed on nitrogen fixed from air. This requires abundant and cheap power. This is a use to which Fushun coal might be put. The ferro-alloys are singularly lacking. Japan has no important supplies of the miscellaneous minerals; and its shortage of sulphur, which it derives only from sulphide ores, is a serious embarrassment to its chemical industries.

Japan is then to a very large extent dependent on imports, and those from long distances. Ocean freight is, of course, cheap, and when the consuming centers are at or near seaboard the shortage may not be a serious matter in ordinary times, except as imports affect the trade balance. However, in time of war, Japan would be extremely vulnerable with respect to its sea-borne trade in essential mineral supplies. This fact in itself must exert heavy pressure for a strong Japanese navy. It should also be borne in mind that a war in which Japan was not involved might very seriously disrupt Japanese industry.

Italy. Italy's situation is much the same as Japan's. By the suggested method of scoring, it has essentially the same rating. Italy's fuel situation is very serious, and it is without any substantial iron ores. Italy does, however, have an outstanding position with regard to several important mineral resources, whereas Japan has none which are more than adequate for its own needs. The sulphur deposits of Sicily are second only to those of the United States. The bauxites of northeastern Italy are exported as indicated by the disparity of the per cent. figures for bauxite and aluminum. Italy's zinc deposits are also important, and the smelting industry in recent years has been enlarged so that Italy now has an exportable surplus.

The list of minerals completely lacking, or essentially so, is formidable and includes coal, petroleum, iron ore, copper, tin, gold, silver, potash, and all the ferro-alloys. Of this list the

fuels are by far the most important, for their lack forces Italy to the manufacture of those products which require the least power and the most manual labor. In supplying Italy's deficiencies, it should be noted that Italy's limited overseas colonies hold little immediate prospect of improving the situation. Italy's policy as to Abyssinia appears to be controlled substantially by the mineral resources of the region of which there is a considerable likelihood of potential development. However the present known resources of the country are slight. Figure 21 shows the territorial control of Africa.

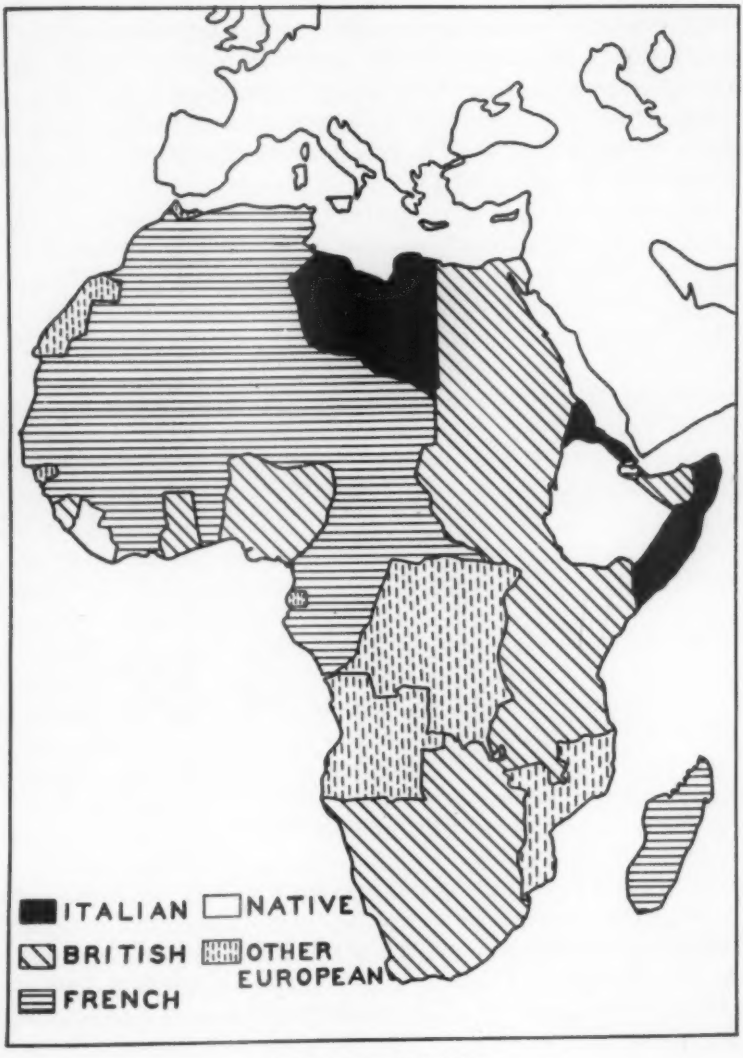
France. France has a total rating of 6.7 which, by the addition of its colonies, as shown in Fig. 19, is increased to 8.5. The outstanding resource of France is the iron ore of Lorraine. In addition to its iron resources, France is the leading country in the production of bauxite much of which is exported. It has adequate supplies of potash, phosphate (from basic slag and from the great deposits of Tunisia and Algeria), and synthetic nitrates, but inadequate supplies of lead and zinc. It is singularly lacking in petroleum, all the ferro-alloys, copper, tin, and the precious metals. No region illustrates better the relation of mineral resources, national policies and military events than northeastern France, western Germany and Belgium. In Lorraine are bedded iron ores dipping westward into the Paris basin. In Westphalia are the best coking coals of continental Europe. In the Saar are large resources of coal, but markedly inferior to the Westphalian coals in coking qualities and therefore in their suitability for steel making. Across southern Belgium and into northern France runs a belt of coal in closely folded rocks, the coal is of good grade but very difficult to mine. At the end of the Franco-Prussian war, Prussia (on the basis of expert engineering advice) fixed the boundary of Lorraine Annexee so as to include all the iron ore which they considered could possibly be reached by mining. The advice was poor, and by 1914 about as much iron was being mined from the French side of the line as from the German, due to improvement in deep mining technique. At the outset of the World War, Germany advanced over the whole Lorraine field and thereby shut off practically all of France's iron ore. Also the advance through Liege, Charleroi, Mons, and Valenciennes shut off nearly all the coal supply.

Figure 22, after Brooks and LaCroix, shows the distribution of the iron and coal fields and steel plants in the region. After the war, the establishment of the Saar district gave France virtual control, for a time, of an important coal field carved out of German territory and greatly supplementing the rather meagre supply of France. However, the Saar coal is not nearly as well suited for coke making as that of Westphalia. Before the war, about 70 per cent. of the Lorraine iron ore went to Westphalia, and the attempt to substitute any coal for that of Westphalia will raise the cost of the finished steel to its disadvantage in a World market. These circumstances forced a trade agreement (the Steel Cartel) almost immediately after hostilities ceased. Relations between France and Germany cannot ignore their mineral resources.[6]

Figure 19 shows the status of France and its colonies. The most striking feature brought out is the tremendous disparity between the extent of the colonies and the very small contributions of mineral products which they have made. There appear to be two explanations for this: the very uncertain control exerted over some territories, such as French Equatorial Africa which is a "sphere of influence" rather than a real colony as well as being so inaccessible that many resources, even if known, would be of little present value; and a second factor, the general policy as regards colonial development. This is perhaps no where better shown than in West Africa where French colonies alternate with British (Fig. 21). In the British colonies of Nigeria, Gold Coast, and Sierra Leone substantial development has taken place, or at least real pioneer work leading toward it. The intervening French territory contains no important mineral resources as yet proved, although apparently having essentially the same chances as the British territory. This state of affairs appears to be the result of past policies, and a very different and firm policy seems to be in effect at the present time. However, it will take much time and continued strong support of the present excellent colonial geological service to

[6] Much of the above is based on an excellent discussion of the problem by A. H. Brooks and M. F. LaCroix, "The Iron and Associated Industries of Lorraine, The Sarre District, Luxemburg, and Belgium," U. S. Geol. Survey Bull. 703, 1920.

FIG. 21.

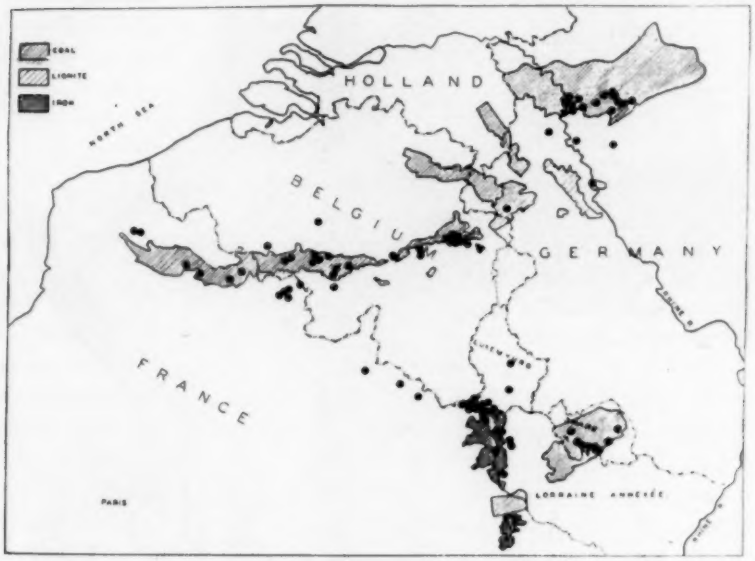


Territorial control of Africa.

bring the more accessible resources of the French colonies up to their potential value.

Germany. Germany, though containing some great mineral resources, is singularly unbalanced. Its rating of 7.3 is equivalent to that of all Asia except U.S.S.R. Germany's coal is the predominant mineral resource upon which directly or indirectly most of its industry has been built. Its long time monopoly of potash is well known, though this has been

FIG. 22.



Iron, coal and steel plants in Central Europe.

cut into by Alsace and Poland and is now seriously challenged by the United States, as well as by Spain and U.S.S.R. Germany's nitrates are all the result of its coal, being partly coke by-product and partly synthetic. Germany has important zinc deposits in Silesia, although it lost a substantial part of this field to Poland. At the present time metallurgical plants are being built to make the fullest use of the German part of the field. Its considerable production of aluminum is again the result of its power resources.

Germany's deficiencies are very great, and it is of interest to see how these were met during the war. Petroleum production has been almost nil; and during the war in spite of production from the Carpathian region (now Poland) and from the Black Sea region, the shortage of petroleum products was keenly felt. In looking toward the future, the potentialities of production from salt dome structures of the German coastal plain are considerable, though as yet to be proved. Iron resources are very small, France and Sweden supplying Germany's wants. The copper resources are trivial in spite of intensive development. Germany's desperate plight in this regard during the war is well known. The need could not be supplied from neutral Scandinavia or from Germany's expanded territory or allies. Tin also is practically lacking, and the supplies of lead are inadequate. Gold production is nil, and silver small. Perhaps the most glaring deficiency is the complete lack of all the ferro-alloys, not only in Germany but in all nearby territory. So great was this lack during the war that vanadium and nickel were actually brought in by submarine. In recent months severe restrictions have been placed on the use of numerous metals for all but the most important uses. Germany, then, though having great strength, has great weaknesses.

British Empire. The general picture presented by the British Empire, as summarized in Fig. 19, is in the most marked contrast to those summaries already considered. The general balance is, on the whole, remarkable. However, it is well to emphasize the geographic scattering which produces the ensemble. The British Isles themselves have abundant coal, moderate iron ore, and almost nothing else. England's industrial position has been built on coal and iron, though the iron supplies are no longer adequate. A measure of the adequacy of individual resources is to compare them to the total per cent. score of the Empire, namely 21. A marked departure from this figure indicates deficiency or abundance. In considering some of these departures we note petroleum, but this lack is perhaps more apparent than real for the Empire has important ownership in foreign fields (e.g. Venezuela and Persia), but such commercial control is by no means national ownership as recent events in Persia have shown.

Copper has been a rather marked deficiency of the Empire, but recent developments in Northern Rhodesia indicate that the 1929 figures of production are no measure of the 1935 status. It is of interest to note that strong official pressure was exerted to keep the control of individual companies well within British hands. Copper production in Canada is also on the increase. The Empire is badly off for the fertilizer minerals. It is extraordinarily well situated as to the ferro-alloys, except molybdenum which is a United States monopoly. Sulphur is singularly lacking.

United States of America. The United States shows many extreme figures, varying from monopoly to complete lack. It has in abundance coal, petroleum, iron, copper, lead, zinc, aluminum (metal), phosphate, molybdenum, and sulphur. Recent developments would probably cause potash to be added to this list. It is deficient in gold and nitrates, and lacks tin, chromite, manganese and nickel; although the production of chromite and manganese can be greatly expanded under war conditions when price ceases to be a controlling factor. Tungsten production has been small but recent developments in Nevada hold promise.

METHODS OF DEALING WITH MINERAL DEFICIENCIES.

The problem of how best to deal with the condition of limited resources is one which confronts every country. No country is entirely self-sufficient and the situation varies from the lack of only a few materials of which the total tonnage required is moderate, as with the United States, to deficiencies so great that the country cannot attempt to become a first class industrial power.

Accept Situation.

The acceptance of the situation is an obvious solution, which, in the case of countries but sparsely endowed, is the wise policy. The fullest development of the resources of the country, other than mineral, may give the country a strong position in international trade such as will allow a substantial measure of prosperity, if war can be avoided. It would seem that the Argentine has followed this course with wisdom and considerable success.

Forced Development of Own Resources.

Any country will, of course, wish to make the most of what it has but in the few countries where the attainment of a large measure of independence is possible, the strongest steps will be taken. This is now in process in the Soviets. At present no one can say the extent to which they can achieve independence. The development at best will be extremely slow not only because of the need of educating a great number of people in new pursuits and in equipping the country to use what it has, but also because the discovery and development of the mineral resources cannot be pushed beyond a certain rate and steps must be taken in an orderly fashion. The full development of a single mining district in most instances involves the development of many mines in succession, as experience and knowledge are gained, and not simultaneously. What the Soviets hold for the future no man can say and much will depend on those mineral resources which the final reckoning will show the country to be without.

In fully developed countries, as the United States, much can be done during periods of emergency, as was shown by the "war minerals." When price does not have to be considered some apparent deficiencies can be made up in this way.

Negotiations for New Territory.

Germany is in the position where the return of its very substantial colonies, lost during the war, would greatly improve its situation. As the country is surrounded by strong powers, any seizure of important neighboring territory is sure to involve a war of the first order. Negotiations seem to be the only recourse.

Trade Alliances.

Trade agreements can stand a serious strain of world upheaval only if the countries are contiguous. Central Europe at present is faced with many such problems with the strongest pressure being exerted against any such moves by the countries adversely affected.

Seizure.

The seizure of new territory is the process by which most strong nations have grown. World opinion in the past has sanctioned such action. At the present time it is unpopular.

Japan is now in process of annexing a substantial part of China. Italy is confronted with a similar situation but has less scope. Ethiopia is the only true native state of Africa left (Fig. 21).

WAR MEASURES.

Seizure.

The capture of enemy industrial centers is an obvious objective in time of war. An instance of such action has been given in discussing German and French relations. However, the situations, where in time of war one country can quickly acquire from its enemy important mineral resources which it lacks, are few.

Stock Piles.

Recently the accumulation of stock piles of supplies of lacking key resources has been advocated.[7] For materials like manganese, chromium, vanadium, tungsten, the ores or the ferro-alloys could readily be stored and thereby a liberal supply could be secured at a very moderate cost, as compared to other military expenditures. The apparent attempt of Japan to stock scrap iron encounters a very different problem because of the quantity of material involved in guaranteeing an adequate supply.

Control of the Sea.

Those countries which must depend upon remote sources for a substantial part of their supply must, of course, be in a position to ensure their delivery even if they have, or can secure, the materials at distant places. Emeny has pointed out two aspects of this problem; the control of the open sea, and the control of the countries own coastal waters. The use of the submarine makes the control of European waters extremely difficult for the assurance of the movement of supplies in the open ocean. These considerations weigh heavily in determining the policy of European nations with constricted routes of access to their coasts; and for Japan, who, though free from a nearby nation with abundant submarines, must be able to protect shipping on the high seas.

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[7] A careful analysis of the situation has been made by Brooks Emeny: "The Strategy of Raw Materials, A Study of America in Peace and War"; Macmillan Co., 1934.

NON-BELLIGERENTS.

Trade in Munitions.

"The developments of peace have fundamentally changed the requirements for war." [8] Munitions, in the broadest sense, are not limited to arms but include the vital raw materials from which the countless requirements of an army are to be made. A large part of the trade with a belligerent will be in materials which in one way or another support the war. Any country which maintains trade with a belligerent supports the war. If trade can be carried on only with one belligerent, the other belligerent may well regard this as an unfriendly act. The perils of such trade have involved the United States in two great European wars. The problems of this country in the event of another European war have been most clearly stated by T. J. Wertenbaker [9] with a view of bringing past experience to bear on future plans. In the past we have drawn "too sharp a distinction between economic war on the one hand and military and naval war on the other. Trade is such a peaceful thing, so necessary, so seemingly legitimate, that one hesitates to call it war at all. War is associated with bursting shells, ruined cities, devastated fields, maimed men, military cemeteries. Yet there have been few wars in which economic pressure has not been a vital or even deciding factor. It was Lincoln's blockade which sapped the strength of the Confederacy; Great Britain's grip on the sea was all-important in bringing Germany to her knees in 1918. So, both in 1793 and in 1914, when we solemnly proclaimed our military and naval neutrality, but without hesitation rushed into the thick of the economic struggle, we placed ourselves in an embarrassing, if not impossible position."

Shipment in Bottoms of Belligerent.

Recently proposals have been made that this country limit its shipment of munitions (in the widest sense) in time of war to ships belonging to the combatants. This removes but one of the dangers, though a great one, of becoming involved

[8] Sir Thomas Holland: "The International Relationships of Minerals"; *International Conciliation*, No. 266, 1931.

[9] "The United States and the Next European War"; Princeton University Faculty-Alumni Forum, 1935.

but leaves us still in a position to play an active part by furnishing supplies.

Withholding Supplies.

Concerted action by all non-combatant major powers in withholding munitions from a belligerent would prevent any major war. Sir Thomas Holland has proposed [10] that there be added to pacts guaranteeing non-aggression a clause that all mineral supplies be withheld from the aggressor. If this were put into effect no great war could last long and the non-combatant population would not be forced to suffer by the withholding of food. However, any embargo against a single country is a very strong measure and may well in itself be considered an act of war.

Economic Neutrality.

The policy proposed by Wertenbaker would limit exports to all belligerents to the amount which they have taken in time of peace. "An embargo against both sides is quite as neutral in a legal sense, and is certainly more neutral in a moral sense, than an unlimited traffic with both sides in death-dealing implements."

United States and British Empire.

Much of the foregoing discussion has been from the point of view of what a nation, the United States in particular, may do for itself during a war between others. In conclusion the writer wishes to emphasize the power for peace which may be exerted by the countries most endowed with mineral resources. To this end the power which the United States and the British Empire can exert, if they choose to act together, is very great indeed. Figure 19 indicates what is possible, and it is particularly notable that the resources of the two supplement each other in a remarkable way, each supplying what the other lacks. The two have an aggregate score of 54, a large number of resources in which they have a commanding position, and

[10] "The International Relationships of Minerals"; British Assoc. Adv. Sci., 1929. "International Movement of Mineral Products in Peace and War"; *Jour. Roy. Soc. Arts*, **78**, 1930. These two papers have been reprinted by the Carnegie Endowment for International Peace, in *International Conciliation*, No. 266, Jan. 1931.

very few deficiencies. Potash is the only serious deficiency in the 1929 figures, and in the United States an adequate supply has now been developed.

ACKNOWLEDGMENTS.

The writer takes pleasure in acknowledging the assistance rendered by Dr. H. H. Hess and Dr. G. R. Heyl and Miss C. M. Rice in accumulating and computing the statistical tables. Mr. G. P. Woollard suggested and made a preliminary summary of table (Fig. 23). Professor A. K. Snelgrove prepared several of the plates.

FIG. 23.

MINERAL PRODUCTION OF RECENT YEARS COMPARED WITH 1929.*

Coal and Lignite.

Year.	Relative Amount of Total Production.		1929.	1933.
		United States	40	33
		United Kingdom	19	20
1929	100	Germany	15	13
1932	72	France	4	5
1933	75	U.S.S.R.	3	7
		Japan and possessions	3	3

Petroleum.

			1929.	1933.	1934. Oil Weekly.
		United States	67	62	61
1929	100	Venezuela	10	9	9
1932	88	U.S.S.R.	7	11	11
1933	96	Persia	3	4	3
1934	100	Roumania	2	4	4

* I am indebted to Mr. G. P. Woollard who first conceived this plan of statement. The column at the left indicates total World production as compared to 1929. The abbreviations used are as follows:

League. Statistical Yearbook of the League of Nations.
Min. Year. Minerals Yearbook, U. S. Bureau of Mines.
Min. Ind. The Mineral Industry during (1933, etc.), New York.
A.B.M.S. Yearbook of the American Bureau of Metal Statistics, New York.
If no source is indicated figures are from the League of Nations, as above.

FIG. 23—*Continued.*

Iron Ore.

			1929.	1933. In Part Estimated by Present Writer.
		United States	37	20
		France	25	33
1929	100	United Kingdom	7	8
1932	38	Sweden	6	3
1933	45	Luxemburg	4	4
		U.S.S.R.	4	15
		Spain	3	2

Pig Iron.

			1929.	1933.
		United States	44	27
		Germany	13	11
1929	100	France	11	13
1932	40	United Kingdom	8	9
1933	50	U.S.S.R.	7	15
		Belgium	4	6
		Japan	2	3

Copper.

			1929.	1933. Min. Year.	1934. A.B.M.S.
		United States	46	20	17
		Chile	16	16	20
	A.B.M.S.	Belgian Congo	7	8	9
1929	100	Canada	6	13	13
1932	47	Mexico	4	4	4
1933	54	Japan	4	7	5
1934	65	U.S.S.R	2	4	4
		North Rhodesia	—	10	12

FIG. 23—*Continued.*

Lead.

			A.B.M.S. Smelter Production Which, for Countries Listed, except Germany, is Essentially Same as Mine Production.		
			1929.	1933.	1934.
1929	100	United States	34	23	22
1932	67	Australia	12	18	15
1933	68	Mexico	10	11	13
1934	77	Canada	9	10	11
		Spain	7	8	6
		India	6	6	5
		Germany	3		

Zinc.

Smelter production for all three years is given as figures for mine production are not available for the two last years given. The ore (or concentrate) may be smelted in a different country than where mined. Note that the figures of Fig. 17 are mine production.

	1929.	1933.	1934. A.B.M.S.
Canada	5	9	10
United States	39	28	28
Mexico	1	3	3
United Kingdom	4	4	4
France	6	6	4
Belgium	14	14	15
Germany	7	5	6
Italy	1	2	2
Poland	12	8	8
Norway	—	5	4
U.S.S.R.	—	2*	2
Japan	2	3	3
Australia	4	5	5

* A.B.M.S.

FIG. 23—*Continued.*

Tin.

			1929.	1933. League	1934. A.B.M.S.
		Bolivia	24	17	18
		Nigeria	6	4	4
	A.B.M.S.	Belgian Congo	1	3	4
1929	100	India	1	3	3
1933	47	Malay States	36	27	30
1934	60	Netherlands, E. Indies	20	15	16
		Siam	5	12	9
		China	4	9	8

Bauxite.

			1929.	1933. Min. Ind.
		United States	17	16
	Min. Ind.	Dutch Guiana	10	12
1929	100	British Guiana	10	5
1932	45	France	30	49
1933	46	Italy	9	8
		Hungary	18	6
		Yugoslavia	5	4

Aluminium.

			1929.	1933. Min. Ind.	1934. A.B.M.S.
		Canada	14	12	9
		United States	37	29	20
	A.B.M.S.	United Kingdom	3	8	7
1929	100	France	11	11	9
1933	50	Germany	12	10	22
1934	60	Switzerland	8	9	5
		Italy	3	9	8
		Norway	11	11	9

FIG. 23—*Continued.*

Gold.

			1929.	1933.	1934. A.B.M.S.
		Canada	10	13	11
		United States	11	10	11
	A.B.M.S.	Mexico	3	3	2
1929	100	Union South Africa	53	49	40
1933	130	Southern Rhodesia	3	3	3
1934	139	U.S.S.R	5	11	15
		Japan	3	2	2
		Australia	2	4	3

Silver.

			1929.	1933.	1934. A.B.M.S.
		Canada	9	9	9
		United States	23	14	14
	A.B.M.S.	Mexico	41	42	40
1929	100	Peru	8	4	5
1933	65	Bolivia	2	3	3
1934	71	Germany	2	4*	3
		India	3	4	4
		Japan	2	4	4
		Australia	4	7*	6

* A.B.M.S.

*Phosphates.**

	1929.	1933.
United States	31	25
French Morocco	13	11
Algeria	6	6
Tunisia	20	18
France	6	?
Germany	5	?
U.S.S.R	1	7
Oceania	8	7

* 1933 on basis of figures on rock phosphate only, but these reduced to figures as shown by assuming same proportion of rock phosphate to basic slag as in 1929.

FIG. 23—*Continued.*

Potash.

			1929.	1933. Min. Year. Estimate.
	Min. Year., estimate	United States	2	9
		Spain	1	4
1929	100	France	18	22
1932	55	Germany	78	61
1933	60	Poland	2	2
		U.S.S.R.	—	2

Chromite.

			1929.	1933. Min. Year.
		Cuba	9	7
		Union South Africa	10	10*
		Southern Rhodesia	42	10
		Greece	4	?
1929	100	Yugoslavia	7	7
1933	54	U.S.S.R.	8	20
		Turkey	2	26*
		India	8	?
		Japan	1	4*
		New Caledonia	8	15

* League.

Nickel.

			1929.	1933. Min. Year.	1934. A.B.M.S.
		Canada	88	86	89
		Greece	1	1	—
1929	100	Norway	1	2	—
1933	82	U.S.S.R.	—	—	1
1934	118	India	1	2	2
		New Caledonia	9	9	8

Tungsten.

			1929.	1933. Min. Year.
		United States	5	7
		Bolivia	10	2
1929	100	India	9	23
1933	73	Malay States	3	10
		China	63	53

FIG. 23—*Continued.*

Manganese.

	1929.	1934. South African Mining & Eng. Jour., Apr. 13, 1935.
Union South Africa	—	2
British West Africa (all or mostly Gold Coast)	12	16
U.S.S.R.	35	34
India	28	18

Molybdenum.

			1929.	1933. Min. Ind.
		United States	93	88
		Mexico	—	2
1929	100	French Morocco	—	2
1933	144	Norway	6	7
		China	1	—

Vanadium.

			1929.	1933. Min. Ind. and Min. Year.
		United States	29	5
		Mexico	1	?
1929	100	Peru	36	—
1933	2	Union South Africa	24	—
		Northern Rhodesia	12	95

Platinum.

			1929.	1933. Min. Year.
		Canada	13	26
		United States	5	1
1929	100	Columbia	20	21
1933	113	Union South Africa	16	4*
		Ethiopia	2	2
		U.S.S.R.	43	46†

* Min. Ind. estimate.
† Based on an estimated production of 100,000 ozs., Min. Year.

FIG. 23—*Continued.*

Diamond.

			1929.	1933.
		Brazil	2	2
		British Guiana	2	
1929	100	Union South Africa	58	12
1933	57	Angola	4	9
		Belgian Congo	25	57
		Gold Coast	9	20

Table of production in 1929 and later years.

Any writer on the general problem of mineral resources and international relations is under obligations to C. K. Leith and H. F. Bain. The present writer has made free use of their published works—he hopes that these gentlemen will not consider the use too free.

SUPPLEMENT.

DEVELOPMENTS SINCE 1929.

Object of Statement.

The following summary of events since 1929 is offered as a supplement to the foregoing rather generalized treatment of the subject. Of necessity it involves discussions of particular districts, with an attempt to evaluate those of likely future importance. This statement may perhaps have some interest as a partial answer as to how much value any attempt to establish relative standing of countries may have when based merely on production figures for a selected year, and not taking into account undeveloped resources of potential importance. In Fig. 23 is given a summary of available figures of production in recent years taken so far as possible from the same source as the figures for 1929 (the League of Nations) so as to have the same standards; however, it has been necessary to use other sources as well, and these are indicated. Figures are as yet inadequate to attempt any general revision of the 1929 rating even for the year 1933. The following summarizes the main events in the more important industries.

Coal.

The most notable change is that of the Soviets whose production from 1929 to 1933 increased 8.2 per cent. in the face of a 25 per cent. decline in World production. Given [11] states that more than half of the output came from the Donetz basin where three-fourths of the coal is now mined with cutting machines and handled by conveyors. Every effort is being made to increase the mechanization of the Soviet coal mines.

Petroleum.

The petroleum industry is notable as a major industry whose 1934 production equaled that of 1929. The United States has lost ground since 1929, its year of greatest production, due to the competition in foreign markets. Soviet production increased 67 per cent., making the Soviets rank second, with 11 per cent. of the World's total. The bulk of this production comes from the Baku region on the west side of the Caspian, but large areas of prospective value are still to be tested in the Soviets. Gubkin, writing in the *Mining Journal* (London) in 1934, refers to "the territory stretching from the borders of Persia, along the eastern shores of the Caspian Sea, taking in the Urals-Eruba district, along the Volga, and reaching the Northern Arctic Ocean" as having great promise.

Iron Ore and Pig Iron.

The great decrease in iron ore mined in the United States, disproportionately great even in the face of a World output less than half of 1929, was due to the continued overproduction of iron ore over furnace requirements in the preceding years of the depression, and to the increased relative use of scrap. This is reflected by the output of pig iron being relatively larger than that of iron ore.

The most noteworthy change in other countries was the greatly expanded production of both iron ore and pig iron in the Soviets, the construction of steel plants being one of the key factors in official plans. Notable in the general plan is the combination of iron ore at Magnitozorsk at the south end of the Urals and coal of the Kuznetsk regions 1200 miles

[11] Given, S. A., Coal and Coke, *The Mineral Industry during 1933*, p. 107.

distant, with steel plants erected in each district. The moving of coal to iron is contrary to usual practice, but in this case is at least movement towards the market. The establishment of a steel plant in the Kuznetsk region raises the question as to how the steel can be economically disposed of from a plant in the central part of Asia.

A region of great potential importance has for a number of years been known to exist in Brazil in the State of Minas Geraes. However, the problem of transportation has as yet prevented its development. Venezuela has recently joined the ranks of iron ore producing countries. The deposits at Pau, close to the Orinoco, are of high grade and large extent and may enter substantially into World trade. Shipments from rich deposits in Sierra Leone have recently been made to England. These deposits may also prove to be of substantial importance. The most spectacular development of iron ores has been in India. Jones [12] has recently described the pre-Cambrian deposits of Bihar and Orissa, not far from Calcutta, which he states have reserves of 4,000 million tons of ore of over 60 per cent. iron.

Copper.

Since 1929 major changes have taken place in the copper industry. The great deposits of Northern Rhodesia, which in 1929 were in the exploratory stage, are now well equipped and producing copper at a very low price. During a period of desperate endeavors to limit production, Northern Rhodesia, Belgian Congo, and Canada went strongly against the trend; Northern Rhodesia, because of the necessity of operating their recently constructed plants, Belgian Congo because of general unwillingness to curtail until bitter necessity forced the measure, and Canada because of the fact that most of its copper has come on the market as more or less a by-product of mining gold or nickel, the metal other than copper exerting the main incentive for mining. During this period the Chilean deposits played an important part in that Chilean copper can be produced profitably at a price which takes most of the joy out of producing copper in Belgian Congo, the producer from the

[12] Jones, H. Cecil, "The Iron-ore Deposits of Bihar and Orissa"; Geol. Surv. India Mem. 63 (2), 1934.

latter country eventually being forced into an agreement as to output. It seems clear that the United States will have great, if not insuperable, difficulty in reëstablishing its former exports upon which the productive capacity has been built. It is of interest to note that the Soviet copper production remains insignificant.[13]

Lead.

Since 1929 one lead camp of the first order has come into production, the Mount Isa district of Queensland; otherwise, the general situation is unchanged. The low relative production from the United States represents the inability to work into accumulated stocks of lead, and also serious competition with secondary (scrap) metal.

Yugoslavia is becoming an important source of lead ore owing to the revival of mining in areas worked by the Romans centuries ago.[14]

Zinc.

Canada has added to the production from the great Sullivan mine in British Columbia, and new production is coming from the Flin Flon mine in Manitoba and from the Rouyn district in Quebec. Canada will increase in relative importance as a zinc producer.

In Germany strong protective measures have been taken for the zinc industry of Silesia and new smelting plants erected.

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[13] After a careful analysis of the Russian copper situation (*Eng. & Min. Jour.* **135**, 547–551, 1934; **136**, 82–87, 1935), C. C. Riddell and G. D. Jermain state (p. 87):

> "It can be safely asserted, however, that the conditions and facts being as here set forth, with an annual primary production not far from 30,000 tons for the past six years, despite strenuous efforts to increase it, and with the supply of scrap steadily diminishing, Soviet Russia will be for some time an importer of copper in large quantities to supply the huge demands of its industrialization program. The present decade, in short, should hold but little Soviet competition for the foreign copper producer. . . . Moreover, should U.S.S.R. devaluate, stabilize, and place its currency on a foreign exchange basis, much of the Soviet ore reserve will be removed to an economic position that will preclude normal competition."

[14] Pehrson, E. W., and Meyer, H. M., Lead, *Minerals Yearbook*, 1934, p. 99.

The bulk of the burden will fall on Poland, who will be deprived not only for a market for a large amount of metal, but also of a source of a corresponding amount of ore; this brings about the necessity of either restricting her own operations by that much, or of securing the necessary ore to maintain production, and what will be more difficult, finding buyers for the metal.

The German industry is kept in operation only through the aid of a government subsidy, as heavy tariffs and depreciated currency in competing countries permit operation at costs prohibitive in Germany.[15]

Tin.

The tin production of the World in recent years has been of an artificial nature due to an agreement of the main producing countries looking towards a restriction of output of one-third of estimated capacity to produce. This resulted in the output for 1933 falling below that of 1900. Prices have risen greatly and in the non-restricting countries, notably Belgian Congo, the industry has flourished.

Bauxite and Aluminum.

The most striking change in the figures is the decrease in output of Hungarian bauxite, apparently a result of Hungary not having reduction plants of its own, and the marked increase in metal production in Germany.

Gold.

Two factors have been effective in a 39 per cent. increase in gold production from 1929 to 1930; changes in the gold standard, which in this country were from about $20 to about $35 an ounce, thus making profitable operations not previously profitable; and the political pressure for production in the Soviets, where ordinary methods of accounting costs do not apply. The Soviets have moved up to second place as gold producers, their output accounting for 40 per cent. of the total increase, while 14 per cent. of the increase came from Canada and 9 per cent. from the United States. The production of the Union of South Africa was almost exactly the same in 1934 as in 1929. This region illustrates well an effect that some economists do not seem to appreciate clearly. An increase in the price of gold, while it greatly stimulates the search for new mines, will not necessarily increase the amount

[15] "The Mineral Industry during 1933," p. 603.

of gold produced from existing large mines. Referring to this region, an editorial of the *Engineering and Mining Journal* [16] summarizes well the conditions.

> The change that has come over the industry is shown by a striking comparison between the 1932 and 1934 operation figures. Tonnage milled increased by nearly five million tons, or 14 per cent.; but the grade fell off 21 per cent. and gold production 9 per cent. At the same time the value of the gold won increased 45 per cent. and the working profit rose more than 100 per cent. Working costs, salaries, and wages rose substantially but did not prevent an increase of 90 per cent. in dividends. The Government's income from leases and higher taxation increased more than 200 per cent.

Silver.

Silver production in the United States declined greatly from 1929 to 1934, in spite of the measures taken to raise the price from an average of 28 cents an ounce in 1932 to 48 cents in 1934, as compared to 53 cents in 1929. The cause of this is that most of the silver mined comes from ores a large part of whose values are in lead, zinc, or copper. The state of the market in the United States for these minerals exerted the major control for the production of silver.

Phosphates.

Again the Soviets appear as the country in which the greatest changes have taken place since 1929. This has been largely by the development of the unique deposits of apatite of the Kola Peninsula. A rough estimate would place the Soviet production as about 7 per cent. of the World's combined phosphates, as compared to but 1 per cent. in 1929. In other countries conditions appear to be relatively unchanged.

Nitrates.

In 1929 the general picture of the nitrate industry showed 64 per cent. of the World total output divided about equally between the natural Chilean nitrates and the synthetic nitrates of Germany, produced largely from atmospheric nitrogen. United States interests hold very large investments in the Chilean industry. The policy of the government of Chile has been to tax the industry to the utmost, and when

[16] Vol. 136, p. 266, 1935. I have changed the figures to the nearest per cent.

the producers offered to reduce their prices to meet World competition if the government would reduce the taxes proportionally, they received no support, with the result that maintenance of the high price aided greatly the construction of synthetic nitrate plants throughout the World. The Chilean industry now finds itself, so to speak, "out on a limb." An interesting analysis of the whole development has recently been made by Bain and Read.[17]

Potash.

The potash industry has been greatly changed since 1929. The most important event has been the beginning of production in New Mexico from potash-bearing strata which for a number of years have been known to underlie a large territory in Texas and New Mexico. The beds, in the district where mined, are extensive and rich. At the same time significant developments have taken place in Spain, near Barcelona; and Soviet production from important deposits on the west flank of the Urals has been pushed vigorously, though as yet without notable effect on World trade. The stranglehold of the German-French Cartel, lately joined by Poland, has been broken. Spanish and German producers contested bitterly for the Netherlands market where, in 1934, the consumption of potash was 36 per cent. more than that of the United States.[18] In the United States, domestic potash furnished 40 per cent. of the domestic requirements in 1933.[19]

Chromite.

In spite of the irregularities of chromite figures, the main change from 1929 to 1933 was the re-entry of two producers who have been out of the picture due to disturbed political conditions since the War; the Soviets with important deposits on the east flank of the Urals, and Turkey with the Smyrna district again producing, as well as a newly developed field to the south. Yugoslavia has joined the ranks of chromite producers. The first production from this country went to Germany during the War.

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[17] Bain, H. F., and Read, T. T., "Ores and Industry in South America"; *Council of Foreign Relations*, 1934, pp. 226–245.

[18] Turrentine, J. W., Potash, *Mineral Industry during 1933*, p. 476.

[19] Idem.

Manganese.

Exact figures are not available for manganese production. However, no marked changes have taken place. Within the last year railroad construction has been planned along the Postmasburg range in the Union of South Africa. It seems likely that the unique and extensive high grade ores of this region will be available before long in the World market.

Molybdenum.

The great deposit at Climax, Colorado, still is without a serious competitor, and the use of molybdenum is increasing greatly as a ferro-alloy.

Nickel.

As with molybdenum, the nickel industry is controlled by the output of a single camp, in this case Sudbury in Ontario. A new find of promise has been made in Finland, but its importance is not yet definitely established.

Tungsten.

The increased production from Burma seems to be well established.

The various Chinese governments have attempted to control output and prices with considerable effect.

The newly developed deposit at Mill City, Nevada, seems to hold promise of substantial production.

Vanadium.

In 1933, the last year for which any statistical information is available, the production of vanadium had nearly ceased due to an over supply of stocks. In Russia some vanadium was recovered from steel slag after giving it a chloridizing roast.

Sulphur and Pyrite.

It is becoming increasingly difficult to compare the output of sulphur from the different sources, native sulphur, pyrite, and smelter fumes. This has been further complicated by the main producer in Spain installing a plant to recover sulphur from a furnace treatment of its pyrite instead of, as formerly, marketing its product as pyrite. Any country

with a well established industry for smelting any sulphide ore has a potential source of sulphuric acid. However, if a market or use for the product cannot be had nearby, the finished acid cannot be shipped far.

Conclusion.

This cursory review of events since the year 1929, on which the main statistical analysis of this paper is based, shows the mineral industry in a healthy state of development. Many changes and shifts have occurred but none of them is revolutionary.

In weighing the importance of changes two factors must be taken into account. Some countries, notably the Soviets, have been able to maintain or even increase output in commodities whose total World production for the period markedly decreased, thereby giving that country a high relative standing which it cannot keep when depression of production in other countries ceases. Secondly, many of the changes that have taken place are in countries already well endowed with other resources—"To him that hath shall be given." The cumulative result, however, of all these changes has but little effect on the rating of countries by the method herewith proposed. No country of minor importance becomes a major importance, or anywhere near it, and the countries in dominant positions remain in essentially the same standing. The main change has been the improvement in the situation of the Soviets. Although they are still far from being a major power with respect to mineral resources, they have the best prospect of substantial improvement of all countries with minor ratings.

The broad lines of mineral control are clearly defined, and a review of events since 1929 serves to show that in spite of active developments the picture is not substantially changed.

THE MEASUREMENT OF COSMIC RAY SHOWERS BY MEANS OF GEIGER-MÜLLER COUNTERS.

BY

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BARTOL RESEARCH FOUNDATION
Communication No. 91.

One of the common methods employed to detect the showers of rays which are produced by cosmic radiation is that of recording the simultaneous discharges of several Geiger-Müller counters so placed that it is impossible for a single ray to pass through all the counters. However, since there must be at least two sensitive areas, we cannot arrange an experiment in such a manner that when a portion of a shower passes through one area, another portion will always traverse the other. Thus only a portion of the showers which occur will be recorded and some estimate must be made of what fraction of the total number are missed. In general, the calculation of this fraction would involve such matters as the solid angle subtended by the counters, the number and distribution in angle of the rays in the shower, and other things concerning which we have little information. The complete solution also involves the solution of a statistical problem. This problem can fortunately be treated in an abstract way and solved despite our present lack of knowledge of the details of shower emission.

Let us suppose that we have a shower of N rays and that it falls upon a system of r counters which constitute our detector. The probability that one of these rays will pass through the ith counter of our system will be determined by the geometrical conditions of the experiment and the nature of the shower producing material. Let us designate this *a priori* probability as p_i, and the number of rays passing through the ith counter as n_i. We also have to consider the *a priori* probability that a ray will miss all the counters, and let us call this p_0. These probabilities then form a complete set, and their sum is equal to unity. We wish to know the

probability that there shall be at least one ray passing through each counter. When the proper values of the *a priori* probabilities are used, the rays of the showers may be considered to occur independently, and the probability of any configuration of rays is given by the familiar multinomial law:[1]

$$\frac{N!p_1^{n_1}p_2^{n_2}\cdots p_r^{n_r}p_0^{n_0}}{n_1!n_2!\cdots n_r!n_0!}, \tag{1}$$

where n_0 is the number of rays which miss all the counters. We have also the relations:

$$\begin{aligned} p_1 + p_2 + \cdots + p_r + p_0 &= 1, \\ n_1 + n_2 + \cdots + n_r + n_0 &= N. \end{aligned} \tag{2}$$

To find the desired probability, expression (1) must be summed over all values of n_i, $1 \leqq i \leqq r$, not equal to zero, subject to the conditions (2).

The summation can be performed successively using the binomial theorem. For the factors containing p_r and p_0 the sum is

$$\sum_{n_r=1}^{N-a} \frac{p_r^{n_r}p_0^{n_0}}{n_r!n_0!},$$

where $a = n_1 + n_2 + \cdots + n_{r-1}$. Multiplying and dividing this by $(N-a)!$ and using the second of the conditions (2) this becomes

$$\frac{1}{(N-a)!}\sum_{n_r=1}^{N-a}\frac{(N-a)!p_r^{n_r}p_0^{N-a-n_r}}{n_r!(N-a-n_r)!},$$

which is a binomial expansion equal to

$$\frac{1}{(N-a)!}[(p_r + p_0)^{N-a} - p_0^{N-a}].$$

The sum over the next factor is

$$\sum_{n_{r-1}=1}^{N-b}\frac{p_{r-1}^{n_{r-1}}[(p_r + p_0)^{N-b-n_{r-1}} - p_0^{N-b-n_{r-1}}]}{n_{r-1}!(N-b-n_{r-1})!},$$

[1] Vide, e.g., T. C. Fry, "Probability and Its Engineering Uses," D. Van Nostrand Co., 1928, p. 65.

where $b = n_1 + n_2 + \cdots + n_{r-2}$. Multiplying and dividing by $(N - b)!$ reduces this to two binomial sums lacking their first terms or

$$\frac{1}{(N-b)!}[(p_{r-1} + p_r + p_0)^{N-b} - (p_r + p_0)^{N-b} - (p_{r-1} + p_0)^{N-b} + p_0{}^{N-b}].$$

This process may be repeated until all the sums are taken.

For the special case of three counters, $r = 3$, and the probability, P, of detecting a shower of N rays is

$$P = 1 - (1 - p_1)^N - (1 - p_2)^N - (1 - p_3)^N + (1 - p_1 - p_2)^N + (1 - p_1 - p_3)^N + (1 - p_2 - p_3)^N - (1 - p_1 - p_2 - p_3)^N, \quad (3)$$

in which p_0 has been eliminated by the first of the conditions (2). In the case where all the *a priori* probabilities, p_i, are equal, the probability of a count may be written in a somewhat simpler form:

$$P = \sum_{j=0}^{r} \frac{r!}{j!(r-j)!}(1 - jp)^N. \quad (4)$$

P vanishes for values of N less than r, and is equal to unity for very large values of N.

Figure 1 shows the variation of P, the probability of a discharge of the counters, with N for several values of p, for $r = 3$. Figure 2 shows, for $p = 0.01$, how P varies with N for $r = 1$, 2 and 3.

The above expressions for the fraction of showers which are detected by Geiger-Müller counters have been checked experimentally and some of their applications and consequences discussed previously.[2]

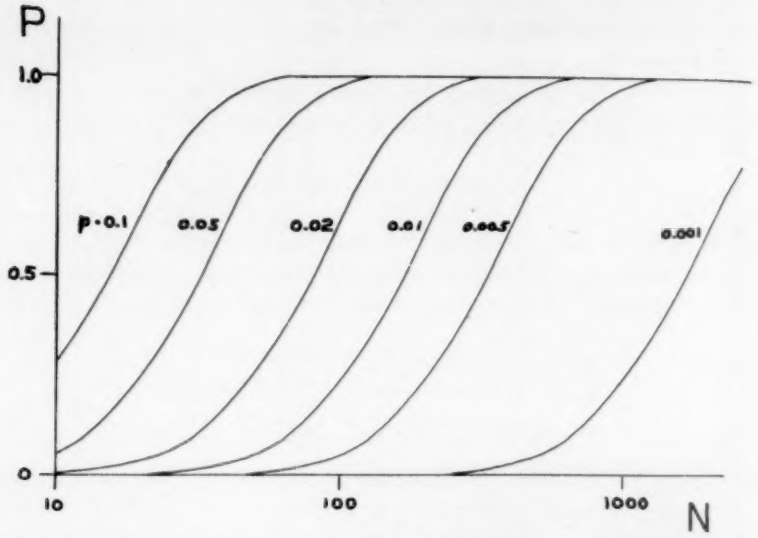
For values of N not too small, an approximate expression [3] for P is useful:

$$P = (1 - e^{-Np})^r.$$

[2] C. G. Montgomery and D. D. Montgomery, *Phys. Rev.*, Nov. 15, 1935.

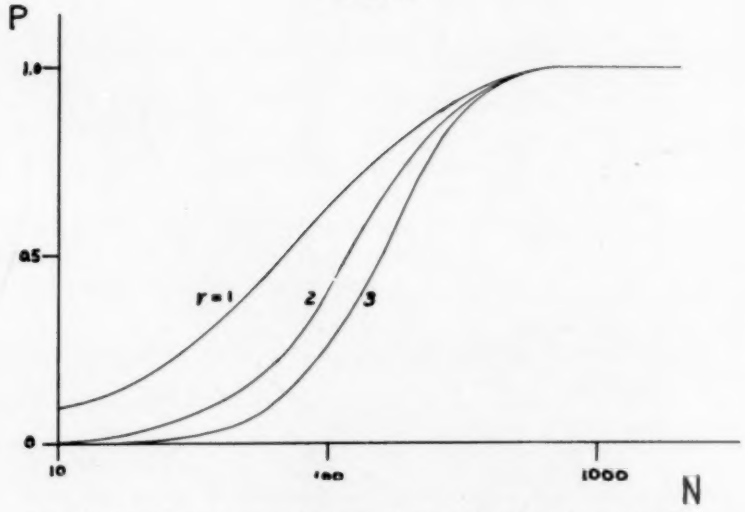
[3] This expression was first derived in an unpublished note by Prof. W. F. G. Swann from somewhat different considerations.

FIG. 1.



The probability, P, that a shower of N rays will discharge three counters whose *a priori* probabilities, p, are equal.

FIG. 2.



The probability, P, that a shower of N rays will discharge r counters for which $p = 0.01$.

If we expand this expression we have

$$P = 1 - r\left(1 - Np + \frac{(Np)^2}{2!} \cdots\right) + \frac{r(r-1)}{2!}\left(1 - 2Np + \frac{(2Np)^2}{2!} \cdots\right) \cdots.$$

Expanding expression (4) we have

$$1 - r\left(1 - Np + \frac{N(N-1)}{2!}p^2 \cdots\right) + \frac{r(r-1)}{2!}\left(1 - 2Np + \frac{N(N-1)}{2!}(2p)^2 \cdots\right) \cdots.$$

which is equal to the above within terms of the order of Np^2.

This approximate form is perhaps more useful from an intuitive point of view, since Np is the average number of rays which pass through a counter when a shower occurs. If this number is small compared to the total number of rays in the shower, the approximate expression may be derived immediately. The probability of having n rays pass through a counter is given by Poisson's law; $e^{-Np}(Np)^n/n!$. The probability of having no rays is then e^{-Np} and the probability of having at least one ray is $1 - e^{-Np}$. Then the probability of a simultaneous discharge of the r counters, since the assumptions made in this approximate derivation render the discharges independent, is $(1 - e^{-Np})^r$. The accurate expression differs from this in that it takes into account those cases in which the fact that one counter is discharged by the shower influences the probability that another will also be discharged.

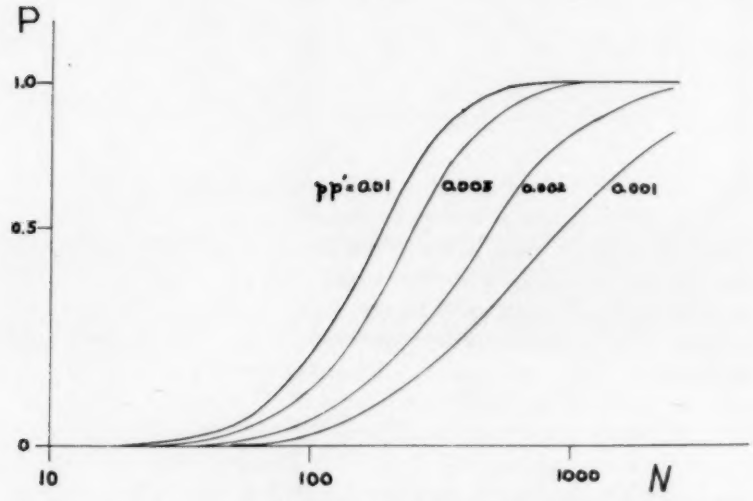
An interesting application of the methods of calculation described here is the problem of the absorption of shower particles. Let us suppose that we have three counters placed out of line, and so arranged that, for showers originating in a mass of material above them, the *a priori* probabilities are $p_1 = p_2 = p_3 = p$. Let us now place a piece of absorbing material over one of the counters. The *a priori* probability for that counter will be altered and will become equal to the *a priori* probability multiplied by the probability, p', that a ray of a shower will pass through the absorber. From

expression (3), the probability of a simultaneous discharge of the counters is then

$$P = 1 - 2(1-p)^N - (1-pp')^N + (1-2p)^N + 2(1-p-pp')^N - (1-2p-pp')^N.$$

For a value of $p = 0.01$, Fig. 3 shows the variation of P with

FIG. 3.



The probability, P, that a shower of N rays will discharge three counters for the case when $p_1 = p_2 = 0.01$ and p_3 has various values.

N for several values of p'. It is to be noted that although these curves are based on the assumption that p' is independent of N, there is no experimental evidence to support this supposition.

The foregoing considerations, then, indicate a basis for the formulation of experimental shower data obtained by means of Geiger-Müller counters. It is hoped that their application will facilitate the solution of the problem of cosmic ray showers.

The authors wish to acknowledge their indebtedness to Professor W. F. G. Swann for fruitful discussions of this problem which grew out of joint investigations with him previously reported.

INTERFEROMETRIC MEASUREMENT OF DOUBLE STARS WITH AN 18-INCH REFRACTOR.

BY

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ABSTRACT.

This paper proves that an interferometer mounted on a moderate-sized telescope can be a useful instrument for measuring close double stars.

By means of an auxiliary tube fitted into the filar micrometer of the Flower Observatory a double slit aperture forming the interferometer was supported 2 feet inside the focus of the telescope. The position angle of the slits could be read from the micrometer circle. From readings of position angles of minimum fringe visibility have resulted many accurate measures in position angle and distance of 44 double stars between 0".1 and 0".6 in distance and down to magnitude 7.5 in brightness.

The interferometer more than doubles the resolving power of the telescope and greatly reduces the inconvenience of poor seeing. Its defects are a waste of light and susceptibility to errors caused by atmospheric dispersion.

Interference methods for the measurement of minute astronomical angles were first traced out by Michelson [1] in 1890. Later Michelson [2] successfully applied these methods to the measurement of apparent stellar diameters. In the similar problem of close double star measurement the advantage of the interferometer over a simple telescope was demonstrated when Anderson [3] checked directly the spectroscopic orbit of Capella. Merrill's work [4] on close double stars marked the close of the earlier experiments, in which were utilized the large Mt. Wilson reflectors.

Less striking but more extensive double star interferometry was shown to be within reach of a smaller instrument, a 12-inch refractor, by the work of Maggini [5] published in 1925. Considering the modest size of his telescope and the difficulty

[1] *Phil. Mag.* V, 30, 1, 1890.
[2] *Ap.J.*, 51, 257, 1920.
[3] *Ap.J.*, 51, 263, 1920.
[4] *Ap.J.*, 56, 40, 1922.
[5] *Pub. R. Oss. Catania*, 1925.

of the pairs observed, the consistency of his measures implied for them truly remarkable accuracy. However, subsequent direct micrometer work has contradicted some of Maggini's measures. The sentiment seems to have spread among double star students that on smaller instruments interferometry is an interesting but unbusinesslike process. The present paper describes an attempt, ten years later, to establish the interferometer as an ordinary instrument for close double star measurement.

THE INSTRUMENT: CONSTRUCTION AND THEORY.

The general set-up of the Flower Observatory interferometer is that suggested by Anderson,[3] namely, slits of fixed separation placed near the focal plane of the 18-inch refractor. For double star measurements with such an apparatus—either of angle or distance—accurate readings of position angles are required. Therefore the Warner and Swasey micrometer was used as a support for the interferometer.

In this micrometer the divided circle is securely attached to the breech-screw, which in turn, when inserted into the telescope tube and turned as far as the interrupted screw will allow, is caught and held by a pin, thus insuring approximate constancy of zero point during a night's work. Inside the breech-screw tube is a close-fitting tube which I shall call the "core" of the micrometer. This is a solid piece of brass, to which the position angle index arms and the box containing the micrometer threads are fixed. Hence there is assurance that the line through the centers of slits attached to the micrometer "core" will have its relative position angle accurately given by the micrometer index arms.

The idea of attaching a piece of paper with slits cut in it directly to the core was first tried but, since the core extends scarcely 3 inches up from the focus, the linear size of the slits was very small. Hence accurate cutting, adjustment, and knowledge of their constants was difficult or impossible, and it was necessary to modify the method. In order to support the slits at a distance from the focus sufficient for them to be of workable size, a piece of iron pipe 21 inches long was turned down on a lathe until it fitted stiffly into the microm-

eter core. To provide for free removal and accurate replacement of slits on the end of the tube, a large thick washer was turned down until it fitted as a plug in the front of the pipe. Constancy of orientation at all joints was assured by index marks on each piece.

The slits themselves were simply apertures cut with a razor blade out of tough, opaque paper, or lead foil. The latter material is to be preferred, as the dimensions of paper may change with dampness. Each pair of slits was then cemented to a separate small washer, which could be attached quickly and in correct orientation to the larger plug washer by means of two short screw bolts. Accuracy of centering at all orientations was made certain by sighting from the focal point, with the interferometer in place, towards the illuminated object glass. In the same way also the slits were oriented parallel to the fixed micrometer thread while being cemented to their respective washers. This relative parallelism always held constant; so the absolute zero reading was determined for the interferometer by merely allowing a star to trail along the fixed micrometer thread.

It can be easily shown by geometrical optics that the effect of slits placed at a distance f inside the focus is equivalent to that of slits placed just outside the object glass and of dimensions F/f times those of the first. Here F, the focal length [6] of the objective, is 315.5 inches and $f = 22.6$ inches, giving the dimension ratio $F/f = 13.96$. Thus, for instance, the diameter of the cone of light from the objective where the slits intersected it was 18/13.96 inches = 1.289 inches = 32.7 mm.

The resolving power of a telescope is limited by diffraction effects of the principal lens aperture, of which the theory is discussed in all texts on physical optics. Thus through an objective of diameter l the central diffraction image of one component of a double star will appear to fall on the first dark ring of the diffraction pattern of the other component when the distance, d, between the pair is

$$d(\text{in seconds of arc}) = 2.44 \frac{\lambda_0}{2l \cdot \sin 1''} \cdot \qquad (1)$$

[6] See *Pub. Lowell Obs.*, Vol. I.

This quantity may be taken as the resolving power, and if we assume λ_0, the effective wave-length of an Ao type star, at 5600 A, it is 0″.32 for the 18-inch.

But the resolving power obtained by using only a small area at each end of a diameter of the object glass is more than twice as great, if one observes the interference, rather than the diffraction, effects. The theory of the interference effects has been worked out in various publications, the most complete treatment being that of H. Spencer Jones.[7] This resolving power is given by

$$d'(\text{in seconds of arc}) = \frac{\lambda_0}{2l \cdot \sin 1''}, \qquad (2)$$

which is less than 0″.14, if the full width of the 18-inch lens could be utilized for slit separation.

The shape of the slits calls for some notice. The object was to get the greatest possible aperture combined with the greatest possible distance between the slits. Figures 1 and 2 show plans of Slits I and II, which were the apertures used most of the time. Slits were always curved on the outside edge to fit the section of the light-cone, and for ordinary use the inside edge, as in Fig. 1, was given a similar curve in the opposite direction in order to add light, symmetry, and distinctness to the interference pattern. However, when the greatest possible distance between slits was required, the inner edges were made straight, as in Fig. 2.

TABLE I.

Characteristics of the Slits.

	Slit I.	Slit II.
Diameter of light-cone	32.7 mm.	32.7 mm.
Diameter of bounding arcs ($2r$)	29.4	30.8
Greatest width of each slit (a)	8.0	4.3
Least width of opaque portion (b)	13.4	22.2
Effective separation (l')	21.4	26.0
$l = l' \times 13.96$	298.6	362.8
d' (for $\lambda_0 = 5600$ A)	0″.189	0″.155
Magnitude of faintest star measurable	7.5	6.0

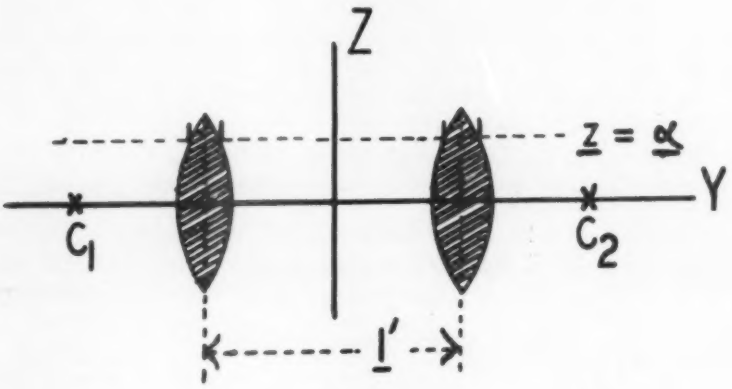
The effective separation of Slit I was taken as the separation of the centers of the apertures. For the unsymmetrical apertures of Slit II the separation was measured between

[7] *M.N.*, **82**, 514, 1922.

the centers of gravity of the areas of the slits. By the usual methods this comes out

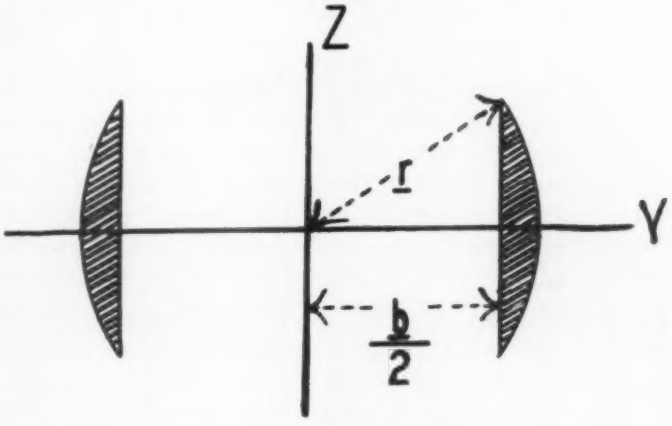
$$l' = \frac{\frac{4}{3}\left(r^2 - \frac{b^2}{4}\right)^{3/2}}{\frac{\pi r^2}{2} - a\sqrt{r^2 - \frac{b^2}{4}} - r^2 \sin^{-1}\frac{b}{2r}}. \qquad (3)$$

FIG. 1.



Plan of Slit I.

FIG. 2.



Plan of Slit II.

The accuracy of this latter procedure is indicated by the fact that if the full lens is considered as a pair of semi-circular slits in contact, the resolving power thus derived is

$$d = 2.36 \frac{\lambda_0}{2l \cdot \sin 1''},$$

while the rigorous diffraction equation is (1).

The modifying effect of finite slit width, discussed by Jones,[7] is negligible for these slits, but an attempt to gain light by using wider slits brought the expected indistinctness to the interference pattern. On the known double stars Slit I gave about the maximum light efficiency and Slit II the maximum distance efficiency.

In deciding what quantity to adopt for λ_0, the first four determinations given in Table II were given most weight. It

TABLE II.

Effective Wave-length of Stars.

Observer.	Average λ.	λ_0 (Ao star).	Instrument.
Schwarzschild, Villiger,[8] 1895	5698 A	.....	Refractor
Comstock,[9] 1896	5704	5638 A	Refractor
Richardson,[10] 1927	5700	5633	Refractor
Richardson,[11] 1928	5661	5633	Refractor
Maggini,[5] 1923	5540	5470	Refractor
Anderson,[12] 1922	5500	.....	Reflector
ADOPTED		5600 A	REFRACTOR

seems to me that the last two are definitely too low for the present purpose. Anderson, using a reflector, should get a lower effective λ, for with this instrument all λ's are brought in focus to the eye, while in the refractor the shorter λ's more than the longer are lost by being out of focus. Maggini made his λ determinations by the method suggested by Anderson,[12] which involves as a direct factor the knowledge of the thickness of a glass plate. Maggini admits that this thickness is

[8] *A.N.*, **139**, 353, 1895.
[9] *Ap.J.*, **5**, 26, 1897.
[10] *J.B.A.A.*, **37**, 311, 1927.
[11] *J.B.A.A.*, **38**, 259, 1928.
[12] *Ap.J.*, **51**, 270, 1920.

only roughly known; and it is found that if a slightly greater thickness, still within the limit of the accuracy he claims, is assumed, λ agrees with that found by other observers using refractors.

However, this consideration does not invalidate Maggini's ratios between wave-lengths for different spectral classes. This list of ratios by which d' must be multiplied in reducing the distance measures for stars of different classes is quoted in Table III from Finsen.[13]

TABLE III.

Spectral class	Bo	Ao	Fo	Go	Ko	Mo
Factor for d'	0.991	1.000	1.005	1.010	1.017	1.028

OBSERVATIONAL METHODS AND RESULTS.

When observing a star with the interferometer, the first care was to see that it was well centered by turning the micrometer box through 360°. A single star viewed under high power with the apparatus appears as sketched in Fig. 3, where the

FIG. 3.

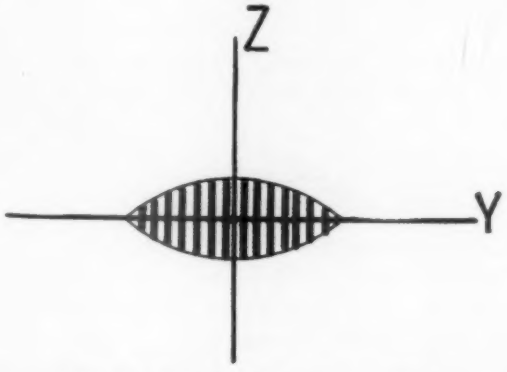


Image of single star given by interferometer.

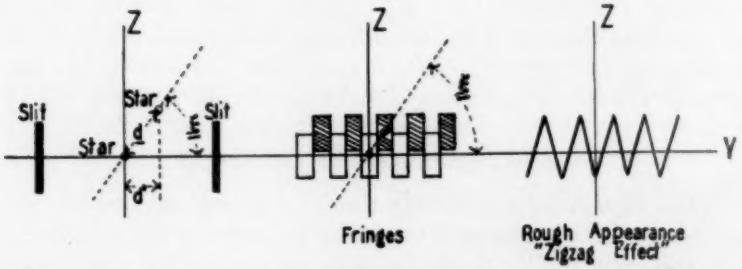
straight lines indicate the interference effects, while the bounding curve outlines the central image of the diffraction pattern. The fringes are perpendicular to the line joining the centers of the slits, so their direction can be changed by rotation of the

[13] *U.O.C.*, **90**, 1933.

micrometer index arm, and their position angle read from the scale of the micrometer. Since these fringes have a separation of only about 0″.35, a power of 1262 was used almost exclusively and for steady work was found to be easier on the eyes than lower powers, even in the worst seeing. The lowest power used for actual measurement was 631.

Figure 4 shows how a double star whose components are at

FIG. 4.



Theory of double star measurement. Relation of stars and fringes at minimum visibility.

least as far apart as the distance from the center of a bright fringe to the center of an adjacent dark fringe would show minima of fringe visibility at four different position angles of the slits, two of the positions differing respectively from the other two by 180°. The rough appearance of the composite image at a minimum is shown. It was proved that this appearance is due to indistinctness by having a myopic person in the laboratory sketch the appearance at ten feet distance of a drawing of the fringes at minimum. The sketch resembled the "zigzag effect" shown here.

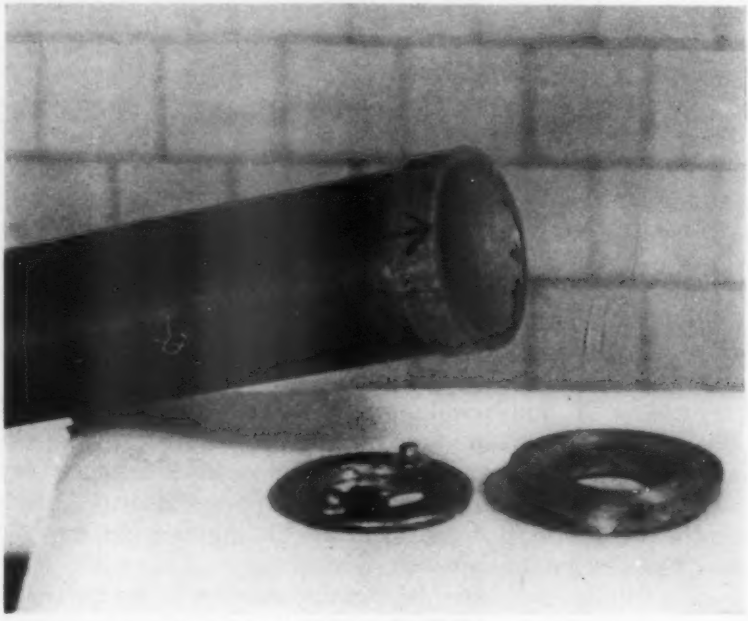
In practice it is best to start observing the star at one of the principal maxima, i.e., when the fringes of the composite image have their greatest apparent length. The position angle p[14] of the stars is about 90° from this point, on a bisector of the angles of intersection of the lines of minima. It will be in doubt by 180° when the stars are equal, of course, and also when the stars are so faint that it is impossible to note the

[14] For the benefit of non-astronomical readers it might be useful to explain that the position angle p of a double star is the orientation of the fainter star with reference to the brighter, measured from the north-point (0°) through the east (90°) to the line through the two stars.

relative brightness of the two sets of fringes. Then if ξ is the angle between p and a minimum, the apparent separation of the double is

$$d = \frac{d'}{\cos \xi}. \tag{4}$$

The measurements are most accurate when $\cos \xi$ varies rapidly with change of ξ and also when the fringe systems have the greatest overlap at the minimum. These two conditions are simultaneously most favorable at $\xi = 30°$ to $50°$, which for the slits used corresponds to $d = 0''.21$ to $0''.28$.



Interferometer tube with slit holders in foreground.

In case the number of minima N between the points 180° apart where the length and visibility of the fringes is greatest is greater than two, the limits of the distance of the pair are given by

$$\frac{3Nd'}{2} \geq d \geq \frac{Nd'}{2}, \tag{5}$$

provided that when N is apparently odd we use $(N + 1)$ in its place, since two of the minima then coincide. However, the half dozen or so stars in the present set of measures for which $d > 0''.4$ and $N > 2$ gave trouble because of errors in

Interferometer tube with slit in place.

determining N and the angles of greatest visibility. This difficulty is owing to the fact that the apparent length of the composite fringes, which is proportional to sin ξ, changes very slowly near the maximum, where $\xi = 90°$, and also to the fact that the central bright fringe is hardly distinguishable from the first one or two on either side of it.

The usual procedure of measurement was to turn the apertures through a complete circle 4 times, thus giving altogether 16 settings on minima (abbreviated "Min."). This observational process would require about 30 minutes of time on the average. The following typical entry, copied from the observing book, shows the method of reduction. Here, as usual, the visibility of the fringes is much better than the seeing. Both are estimated on a scale of 5. The typical internal probable error of p is about $\pm 2°.0$ and for d about $\pm 0''.02$.

Oct. 12, 1934 = 34.780

ADS 102 Spectrum A3

Slit I, d' = 0".189
Eyepiece = 1262
Hour angle = 6h
Seeing = 1
Visibility = 3

	Position Angles			
	Min. 1	Min. 2	Min. 3	Min. 4
	310°.5	217°.3	133°.5	46°.7
	320.3	211.5	121.2	52.5
	311.4	216.5	126.7	32.1
	306.0	214.3	128.6	34.0
Means =	312°.0	214°.9	127°.5	41°.3
	p_1' = 263°.4	= 83°.4,	p_2' =	84°.4
				83.4
	ξ_1 = 48°.6		p' =	83°.9
	ξ_2 = 43.1		Zero point =	−5.3
Mean ξ =	45°.8		p =	78°.6

$$d = \frac{.189}{\cos \xi} = 0''.272$$

When d is less than d', it is estimated from the degree of narrowing of the fringes. Such an observation is not trustworthy when zenith distances much exceed 45°, for then atmospheric dispersion, which varies as the tangent of the zenith distance,[3] begins to have an appreciable effect. Each bright fringe is widened into a short spectrum, so there is an apparent narrowing of dark fringes in all stars when the fringes are turned parallel to the horizon, and in measuring double stars the position angles are attracted towards the vertical. However, the effect seems to be negligible at moderate zenith distances, as indicated by the fact that measures taken when p was near the vertical showed no systematic difference from those made at a different hour angle.

Observations of minima on pairs differing by more than one magnitude in brightness are uncertain. Such doubles should be left to the micrometer. Observations of stars at large zenith distances (some of them actually single stars) and of doubles with components of very different magnitudes probably contributed several spurious measures to Maggini's publication.[15]

As another precaution against gross error it is necessary to insure that no part of the objective is covered by the dome, for then a minimum will occur in the position angle at which the overlapping exists. Some of the interferometer measures were checked micrometrically on the same night.

[15] Loc. cit., e.g. βGC 1659, 1887, 2279, 2314, 4714, 13203. Cf. entries for these stars in ADS (Aitken's Double Star Catalogue).

TABLE IV.

The Measures.

ADS.	Mags.	Sp.	Date.	*p.*	*d.*	*n.*
102	6.3–6.6	A3	34.806	79°0± 0°7	0″.27±0″.01	3
434*	5.6–5.9	B8	34.964	175.4± 5.1	0.49±0.03	2
490	5.6–6.4	Go	34.751	240.7± 6.3	0.27±0.01	3
520*	6.4–6.4	Ko	34.598	73.6± 5.8	0.25±0.03	2
784	6.1–6.8	B9	34.921	43.5± 1.2	0.16±0.02	3
940	4.9–6.5	B8	34.964	184.1± 0.6	0.29±0.01	2
2336	6.1–6.1	B8	34.768	.....	<0.10	3
3064*	5.8–6.1	Fo	34.838	.....	<0.10	1
3182	5.9–5.9	A2	34.982	115.3± 8.1	0.13±0.02	2
3380*	5.7–6.0	Ma	34.850	.....	<0.10	4
Capella	0.8–0.8	Go	35.000	.....	<0.10	2
3701	6.0–6.0	Go	34.862	106.2± 1.1	0.09±0.01	3
3799	6.5–6.7	A2, G	34.874	.....	<0.10	2
3823BC	8.7–8.7	A	35.087	.....	<0.10	1
Boss 1559*	6.2–6.2	A5	34.860	136.6± 0.9	0.27±0.01	3
4866	6.6–6.6	B9	34.831	3.8± 1.5	0.32±0.02	3
4929	7.5–7.5	A3	34.838	137.0	0.24	1
6354	7.2–7.2	F5	34.838	23.0	0.13	1
6650AB*	5.6–6.0	Go	34.999	167.9± 6.7	0.68±0.04	2
6993	4.0–5.5	F8	35.102	127.6±21.3	0.23±0.01	2
7158	4.0–4.2	Ao	34.961	122.0± 0.1	0.20±0.01	2
			35.018	111.5± 1.7	0.20±0.01	2
7545	5.0–5.6	A2	35.052	343.4± 4.0	0.45±0.01	4
7780*	4.0–6.5	Ko	35.385	224.8± 2.5	0.57±0.04	4
8804	5.2–5.2	F5	35.146	18.8± 1.3	0.58±0.03	4
8987*	6.0–6.0	F2	34.772	180.4± 0.8	0.27±0.01	4
9301	6.3–6.5	A2	35.293	191.1± 0.5	0.28±0.01	3
9505	6.7–6.7	Ao	35.220	284.1± 4.2	0.12±0.02	2
			35.382	.....	<0.10	2
9617	5.6–6.1	Go	34.567	233.0± 0.8	0.41±0.01	4
9688	5.5–5.5	A2	35.292	.....	<0.08	2
9716	7.0–7.3	Ko	34.559	319.1± 2.3	0.31±0.03	3
9744	5.2–5.2	A2	35.364	261.9± 1.4	0.19±0.01	3
10087	4.4–5.3	Ao	35.251	160.2± 0.7	0.38±0.01	3
10360	6.0–6.0	A5	34.629	259.0± 9.1	0.10±0.01	4
10531	7.0–7.1	F8	35.064	266.2± 3.2	0.31±0.04	2
Nova Her*	7.0	.....	35.650	See note	0.20 : (disc)	3
11468	6.0–6.0	Ko	35.438	44.2± 1.7	0.20±0.01	4
14499	5.7–6.2	F5	34.590	291.7± 1.7	0.25±0.01	3
14761	7.0–7.0	A5	34.735	151.9± 2.7	0.26±0.02	3
14773	5.3–5.4	F5	34.578	11.9± 1.9	0.16±0.01	4
			34.826	350.2± 7.6	0.10±0.01	3
14859	6.0–6.0	F2	34.548	.....	<0.08	1
15281	4.8–5.3	F5	34.748	279.9± 1.8	0.18±0.01	7
16173	6.3–6.9	G5	34.644	40.6± 1.3	0.51±0.02	3
16497	6.0–6.0	Fo	34.720	178.3± 3.1	0.23±0.02	4
16836	6.0–6.0	K2	35.005	214.9± 1.5	0.42±0.04	3

* *Notes:*

434. . There was an additional night's measure divergent by 0″.5 in *d*, so that it seemed safe to reject it.

In Table IV, which gives the means of double star measures made on n nights, there are given in connection with p and d the probable errors computed by the usual formula,

$$0.6745\sqrt{\frac{\Sigma v^2}{n(n-1)}}, \tag{6}$$

where v is a residual from the mean.

Table V gives the differences of interferometer measures from the most recent available micrometer measures made on n nights by the observer noted, on the date and with the telescope given. In this connection thanks are due for measures communicated to me in advance of publication by

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520..Zenith distance always $> 65°$; probably atmospheric dispersion has made the position angle too small.

3064..Duplicity was certain, although measurement impossible. Voronov computes $d = 0''.08$ (Bull. Tashkent Obs. 4, 1934).

3380..This star was measured as a double at 190° on 2 nights, but the measures were rejected when it was found that two nearby single stars showed minima at the same position angles. This effect is probably due to atmospheric dispersion at a zenith distance of $> 60°$.

Boss 1559..Found double by Kuiper (*Pub. A.S.P.*, 46, 190, 1934).

6650..Measures untrustworthy. The micrometer is more efficient for such a wide double.

7780..The first 8 nights of observation on this star yielded measures which have been rejected as being grossly in error, owing to a combined effect of the inconveniently great distance and the 2.5 magnitude disparity between the components. The given measures are trustworthy, but only because they were checked on the same night with a micrometer. For such a double the micrometer is more efficient.

8987..One additional night's measure has been rejected because of a 41° divergence in p from the mean. On this night the star was over 4 hours west and since its declination is $+11°$, the zenith distance must have been $> 60°$. Atmospheric dispersion might have produced the observed positive deflection of position angle.

Nova Her..This star was observed on several nights during the primary maximum and showed fringe effects just like an ordinary single star. On 3 nights as tabulated, during the secondary maximum, the fringes were visible at all position angles, but very indistinct compared to those on nearby stars of similar brightness. This observation could be explained by assuming the object to consist of a bright, roughly spherical nebulosity, at least $0''.20$ in diameter, and having a central condensation not quite stellar in intensity.

Dr. Aitken (A) with the 36-inch Lick refractor, and by Professor Van Biesbroeck (VBs) with the 40-inch Yerkes refractor.

Likewise Table VI gives the residuals from orbits published where noted by the computer given. Here precession (maxi-

TABLE V.

Comparisons—Interferometer Minus Micrometer.

ADS.	Date.	$\Delta\rho$.	Δd.	n.	Aperture.	Observer.
102....	32.619	−0°.5	0".00	2	40 in.	VBs
434....	31.72	12.5	0.06	3	8	Phillips
490....	33.89	8.4	0.03	2	36	A
	34.96	−20.3	0.01	1	36	A
520....	32.878	−3.5	−0.01	6	26½	Van den Bos
784....	34.210	28.7	−0.04	2	40	VBs
940....	33.25	1.9	−0.07	4	36	A
4866....	31.38	0.6	0.06	4	36	A
6650....	32.96	18.4	0.14	3	8	Phillips
6993....	33.308	−7.5	0.01	4	26½	Van den Bos
7545....	31.218	5.2	−0.21	2	40	VBs
7780....	34.236	7.4	0.12	3	40	VBs
	35.414	0.4	0.00	2	18	Wilson
8804....	35.261	8.8	−0.04	4	18	Wilson
8987....	34.53	1.3	0.08	2	36	A
9301....	34.46	2.6	0.07	2	36	A
9617....	34.57	−1.8	−0.09	4	8	Phillips
9716....	34.478	4.6	−0.04	5	18	Wilson
10087....	35.427	1.9	−0.09	3	18	Wilson
10531....	25.61	−0.6	−0.01	1	30	Paloque
14499....	34.610	−1.4	−0.07	3	40	VBs
14761....	33.663	0.3	0.00	3	40	VBs
16173....	34.161	−4.9	0.04	4	40	VBs
	34.832	0.9	0.03	3	18	Wilson
16497....	34.73	3.7	0.05	3	36	A
16836....	29.61	17.0	−0.04	1	36	A

mum 0°.2) has been neglected, and in all cases the century is omitted from tabulated dates.

The 18-inch refractor was at my disposal for measurement of these 44 stars on about 1/4 of the total observing time between July 1, 1934 and Sept. 1, 1935. Practically all observing was done in the second half of the night, which compared with the first half has worse seeing and is shorter, since it starts at 1 A.M. In the interval between the dates given the interferometer was successfully used on 45 nights. On only 5 nights was its use wholly impossible because of bad seeing, although the average seeing was 2 on a scale of 5.

On the suggestion of Dr. Olivier nights on which measure-

TABLE VI.

Comparisons—Interferometer Minus Orbit.

ADS.	Date.	Δp.	Δd.	Computer.	Publication.
102..	34.80	18°.4	0".01	Van Arnam	Union Obs. Cir. 91
490..	34.751	−2.0	−0.02	Luyten	U. O. C. 91, 1934
520..	34.598	−21.3	−0.22	Aitken	U. O. C. 91
3701*.	34.862	49.0	−0.03	Voronov	Tashkent O. C. 27, 1934
4929..	34.838	−12.4	−0.02	Van den Bos	U. O. C. 91
6650..	34.999	33.1	0.04	Makemson	U. O. C. 91
6993..	35.102	−20.6	0.00	Aitken	U. O. C. 91
7545..	35.01	2.8	−0.03	Voronov	Tashkent O. C. 27
8804..	35.146	5.8	0.09	Voronov	Tashkent O. C. 27
8987..	34.772	2.7	0.03	Voronov	Taskhent O. C. 27
9301..	34.50	17.2	0.06	Young	U. O. C. 91
9617..	34.567	−1.1	−0.09	Silbernagel	U. O. C. 91
9716..	34.559	−1.3	0.00	Komendantoff	Pulkowa O. C. 8, 1933
10087..	35.251	11.5	−0.09	Van Biesbroeck	U. O. C. 91
10360*.	34.629	101.5	0.02	Aitken	U. O. C. 91
14499..	34.590	0.5	−0.04	Van den Bos	U. O. C. 91
14773..	34.59	1.3	0.02	Aitken	U. O. C. 91
	34.83	0.7	0.03	Aitken	U. O. C. 91
15281..	34.748	6.0	0.04	Luyten	Ap. J., 79, 449, 1934
16173..	34.644	13.1	−0.18	Van den Bos	U. O. C. 91
16497..	34.69	3.5	0.03	Aitken	U. O. C. 91

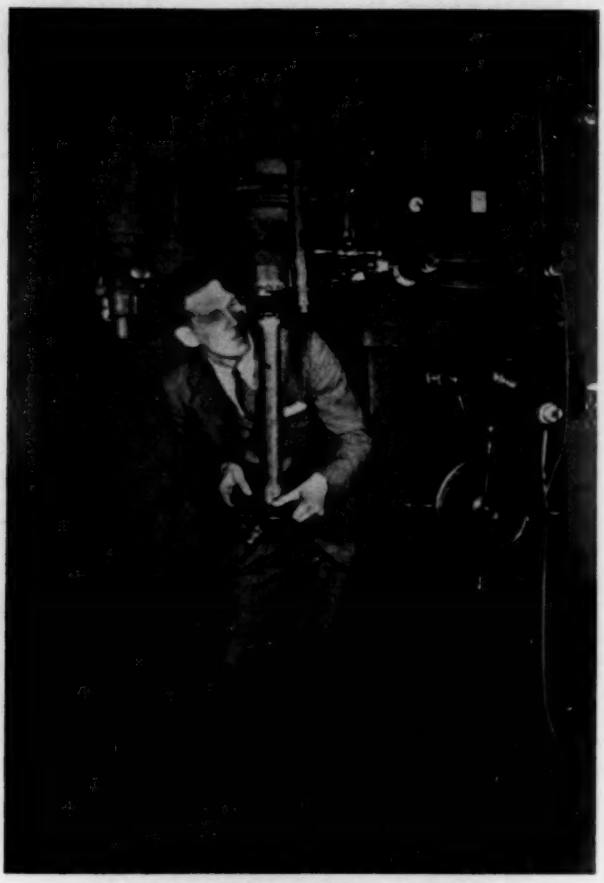
* *Notes:*

3701..Preliminary orbit, P = 5.3 years. Voronov's notation leaves the direction of motion unexpressed; direct motion gives this smaller residual.

10360..Increasing the period of 15.5 years by less than a year should absorb this large residual.

ment of known doubles was impossible because of haziness or moonlight were utilized in scrutinizing for duplicity some 45 of the brighter naked-eye stars, catalogued as single. No new double was found among these, although the chances were more than even of noticing a double separated by more than 0".10 in distance and less than one magnitude in brightness. In such a search a telescope with an interferometer should have the advantage over even much larger telescopes used at full aperture, for although the troublesome glare of a bright star can be cut down by placing a screen over the eyepiece, the seeing is always better in the interferometer because of its smaller aperture. Also, since about ten fringes are conspicuous on a bright star, and these could all be made to disappear simultaneously if the star had equal components only 0".15 apart, the observational phenomena with the interferometer are clearly more striking, and a double of such closeness would less easily be missed.

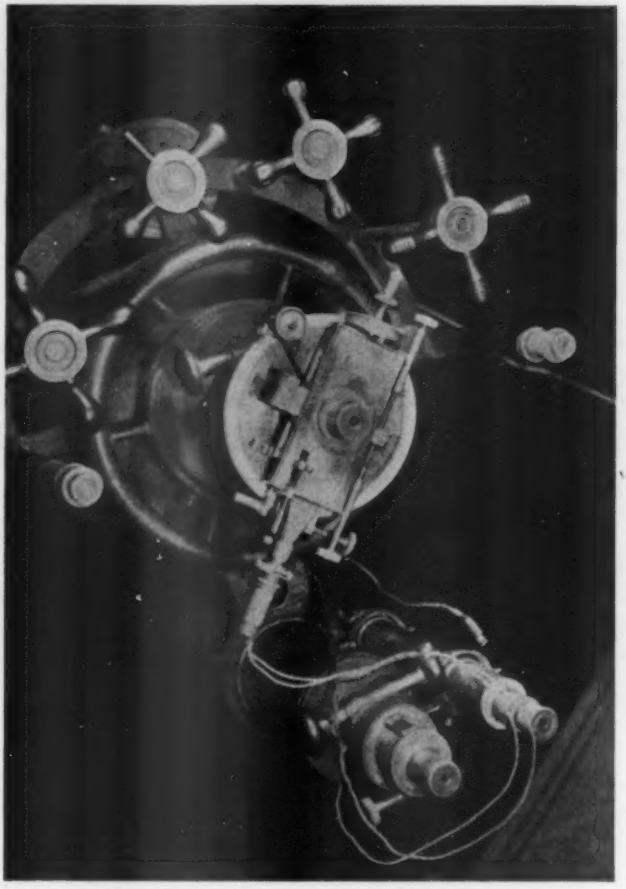
On the whole, the interferometer has proved a practically successful measuring instrument in the field of bright, nearly equal, double stars below the limit of comfortable resolution for direct micrometer observation. Its use is less easy and



Insertion of interferometer into 18 inch refractor.

less rapid than that of an ordinary micrometer, but there are compensations in the greater interest of the doubles within reach of it and its greater utility in mediocre seeing. Its greatest disadvantage is lack of sufficient starlight, and as this difficulty was increased in the present case by much poor see-

ing and the illumination of the sky due to the lights of Philadelphia, most observatories should find such measurements even more satisfactory.



Eyepiece end of 18 inch refractor with micrometer.

In conclusion, I am indebted to Mr. John W. Evans, then of Flower Observatory, for invaluable aid at the inception of this research, especially in the theory and construction of the instrument.

A Twelve- or Thirteen-Month Calendar?—Whether the calendar shall be revised to the point of replacing our present year of twelve months with one of thirteen has been a matter of speculation for some few years. A blow to the thirteen-month idea apparently was dealt at the recent Seventh American Scientific Congress which just concluded its quadrennial meeting in Mexico City. At a request from the Mexican government for support on a plan for a revised calendar, a Congress committee pledged such and recommended that the government proceed at once, in the League of Nations, to obtain official adoption of a new calendar in 1939.

The proposed plan, "while retaining the 12-month division of the year, groups the months into cycles of 31, 30 and 30 days, obtaining in this way an absolute equality of the four quarters of the year with 91 days in each quarter, and also a relative equality of all the months, since all will contain 26 week days and the only difference lies in the fact that the first months of each quarter have an additional Sunday." Since such an arrangement accounts for only 364 days, a special "Year Day" will be included in all years with another extra day in leap years.

C.

"Michael Faraday gave the following as a definition of the correct attitude of a research worker: 'The scientist should be a man willing to listen to every suggestion, but determined to judge for himself. He should not be biased by appearances; have no favorite hypothesis; be of no school; and in doctrine have no master. He should not be a respecter of persons, but of things. Truth should be his primary object. If to these qualities be added industry, he may indeed hope to walk within the veil of the temple of nature.'"—T. A. Boyd, "Research."

THE OPERATING CHARACTERISTICS OF SMALL GRID-CONTROLLED HOT-CATHODE ARCS OR THYRATRONS.*

BY

HOBERT W. FRENCH, JR., A.B., S.M.

ABSTRACT.

The grid current required to fire a thyratron has been shown to depend theoretically upon the shape of the grid current characteristic before firing as well as upon the grid circuit constants. The three-element FG–17 and the four-element FG–95 and FG–98 thyratrons have been investigated. Anomalies where excessively large grid currents were required to start the arc, occurring below certain values of temperature and plate potential, have been found and are described in some detail. Although the argon-filled FG–98 was found to be free from temperature effects over the operating range, positive shield grid potentials ntroduced anomalies at low plate potentials. Even though the plate and shield potentials and the temperature were kept within the recommended optimum range, it was found that for minimum grid currents at firing the negative grid impedance of these tubes necessitated a grid resistance of 100 to 1000 megohms.

INTRODUCTION.

In the grid-controlled arc or thyratron, which contains mercury vapor or inert gas at a few microns pressure, the grid does not exercise continuous control of the plate current as in the high vacuum triode, but merely governs the starting of an arc. As has been shown by Nottingham,[1] the current in the grid circuit of a thyratron before starting is not zero, but is very similar to the grid current in a "gassy" vacuum tube. Although this current is very small compared with the plate current after discharge, it is exceedingly important in certain applications such as the control of a thyratron by a photocell in the grid circuit. The purpose of this investigation was to determine the magnitude and nature of these grid currents, so that the current amplification of the thyratron might be utilized more fully. When the thyratron is used at its

* Condensed from a thesis of the same title submitted in partial fulfillment of the requirements for the degree of Master of Science in Physics from the Massachusetts Institute of Technology.

[1] W. B. Nottingham, JOUR. FRANK. INST., 211, 271 (1931).

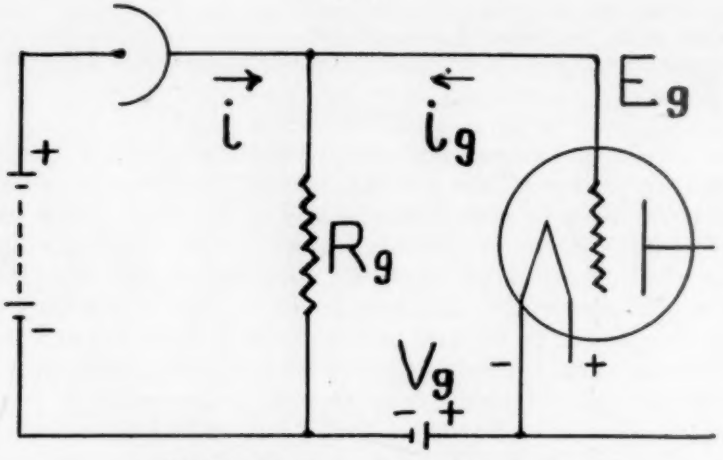
fullest sensitivity, various factors affect its reliability of operation. Hence, the effects of changes in temperature, voltage, and other external conditions upon the starting characteristics have been studied, and are reported below.

THEORY OF THYRATRON GRID CIRCUITS.

The manner in which the grid potential controls the starting of the arc in a thyratron has been thoroughly discussed by Hull and Langmuir.[2, 3] In brief, when the grid potential is made more positive than a certain critical value, the discharge begins. The relations between grid potential, grid current and the grid circuit constants, described in detail by Nottingham [4] for the vacuum tube, may be adapted with only slight modification to the thyratron characteristics before the discharge starts.

Figure 1*a* shows a conventional circuit, in which an in-

FIG. 1*a*.



Circuit for controlling thyratron by photocell.

crease in the amount of light falling on a photocell causes a thyratron to operate or "fire." A grid bias V_g is chosen such that the grid potential E_g will have a value slightly

[2] A. W. Hull and I. Langmuir, *Proc. Nat. Acad. Sci.*, **51**, 218 (1929).
[3] A. W. Hull, *Gen. El. Review*, **32**, 213–23, 309–99 (1929).
[4] W. B. Nottingham, JOUR. FRANK. INST., **209**, 287 (1930).

more negative than the critical grid potential. A photocell current i, flowing in the direction shown, will cause an increased potential drop across the high resistance R_g in such a direction as to make E_g more positive. If the increase is great enough, E_g will reach the critical potential and the tube will fire. The sensitivity of this circuit, the rate of change of E_g with i, may be found from the Kirchoff Equation of the circuit, where i_g is the current flowing in the grid circuit proper.

$$E_g = V_g - (i + i_g)R_g. \tag{1}$$

Differentiating, and remembering that the impedance Z_g is defined by the relation

$$\frac{1}{Z_g} \equiv \frac{di_g}{dE_g}, \tag{2}$$

the sensitivity is

$$-\frac{dE_g}{di} = \frac{R_g}{1 + \frac{R_g}{Z_g}}. \tag{3}$$

The negative sign indicates that an increase in the photocell current, the independent variable, decreases the magnitude of the negative grid potential.

The grid current i_g and its rate of change with grid potential, the reciprocal of the grid impedance Z_g, were actually determined by the method described by Nottingham [1] using the circuit in Fig. 1*b*. The Kirchoff Equation of this circuit is

$$E_g = V_g - i_g R_g, \tag{4}$$

where V_g in this case is not constant, but the independent variable. The sensitivity here is

$$\frac{dE_g}{dV_g} = \frac{1}{1 + \frac{R_g}{Z_g}}. \tag{5}$$

The grid impedance Z_g at any particular grid voltage may be either positive or negative. If the grid impedance is positive, the tube will fire when

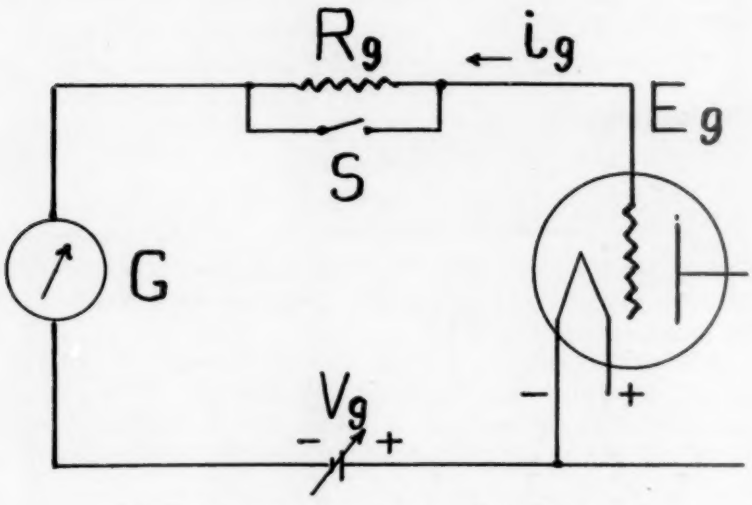
$$i_g R_g - V_g = \text{critical grid potential}. \tag{6}$$

If, however, the grid impedance is negative and approaches the magnitude of R_g, the rate of change of grid potential then becomes infinite, for the denominator of equation (5) approaches zero. Should this occur in the neighborhood of the critical potential, the tube will fire.

METHOD OF MEASURING GRID CURRENT AND IMPEDANCE.

The circuit in Fig. 1*b* can be used to measure both the impedance and the grid current at firing. The grid current

FIG. 1*b*.



Circuit for measuring grid current characteristics of thyratrons.

is read on the galvanometer G for various values of grid bias, starting at large negative voltages and increasing the bias to within a few thousandths of a volt of the critical potential. With the high resistance R_g shunted out of the circuit, the remaining resistance is so low that the voltage drop may be neglected, and the bias V_g may be taken as equal to E_g.

The resistance method described by Nottingham [1] was used for determining the grid current at firing. If V is the value of the grid bias at which the tube fires with zero resistance in the circuit, and V' the critical bias with R_g in the

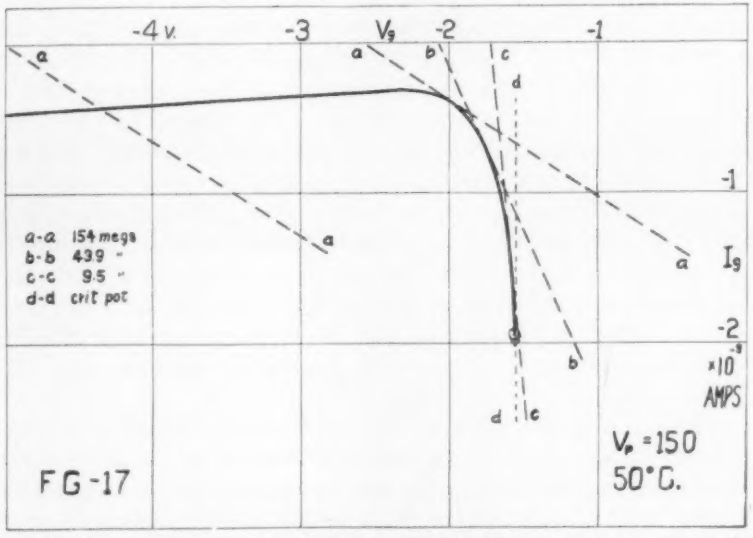
circuit, then the grid current at firing is

$$I_g = \frac{V' - V}{R_g} . \tag{7}$$

This equation (7) always gives the correct value of the grid current at firing when the grid impedance is positive, but if the impedance is negative this gives the correct value only when R_g is less than the magnitude of the impedance.

Figure 2 shows a typical curve of the grid current in an

FIG. 2.



Shape of typical normal grid current characteristic, with dashed lines having slopes corresponding to 154, 43.9 and 9.5 megohm grid resistances.

FG–17 before firing, as a function of the grid bias. The current was measured on a galvanometer with a negligible resistance in the grid circuit up to within 0.02 of a volt of the firing potential, shown by the dashed line *d–d* in the figure. The reciprocal of the slope of the solid grid current curve at a particular point gives the grid impedance at the voltage corresponding to that point. In this curve, the impedance is positive from -5 volts to approximately -2.25 volts, and negative from there on to the firing point.

The dashed line *a–a* at the left in Fig. 2 has a slope which

is the negative reciprocal of the grid resistance used, 154 megohms. The intercept of this dashed line on the voltage axis is the grid bias, V_g in Fig. 1*b*, and the intersection of this line with the solid grid current curve gives the grid current and grid potential. In this case, with a grid bias of -5 volts, the grid potential is about -4.35 volts. As the grid bias is made more positive, the line is displaced to the right, keeping the same slope.

At a grid bias of about -2.50 volts this line becomes tangent to the grid current curve, and the negative impedance becomes equal in magnitude to the grid resistance. This is the condition for which the denominator of equation (5) becomes zero, and the rate of change of grid potential with grid bias becomes infinite. In the graph, the grid potential is no longer given by the intersection of the dashed line and the curve, but being unstable at the point of tangency, follows to the right along the dashed line until it crossed the critical voltage *d–d*, when the tube fires. The grid current calculated by the resistance method corresponds to the intersection of the dashed line and the critical potential, but the grid current required of a photocell to fire the tube is given by the point of tangency, and is actually slightly smaller than the calculated value. The resistance lines for 43.9 and 9.5 megohms are represented by *b–b* and *c–c*.

Since the three types of tubes tested all had grid current curves of this shape, the resistance method gave the correct value of the grid current only when resistances of one megohm or less were used. With these small values, the difference $V' - V$ of equation (7) was of the same magnitude as the fluctuations of the critical grid potential inherent in this kind of tube. Hence it was more satisfactory to trace the grid current with the galvanometer up to within one-thousandth of a volt of the critical potential, since the real value of the grid current required to fire the tube could then be determined for any resistance from the point of tangency.

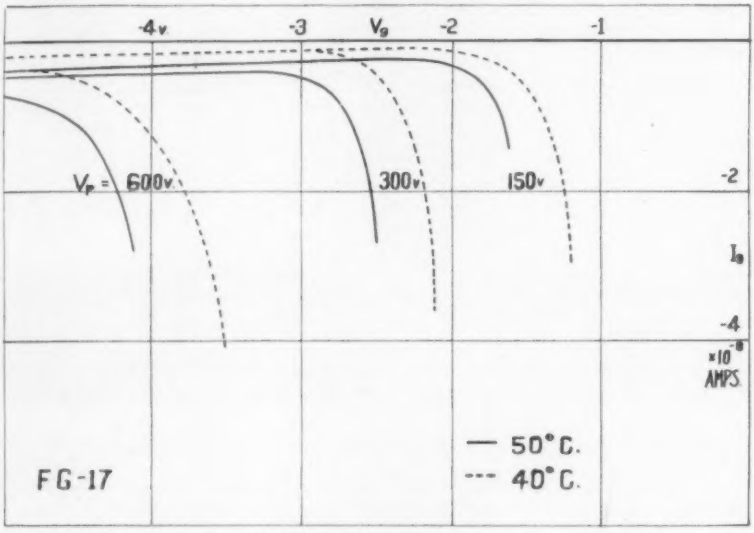
CHARACTERISTICS OF FG–17.

Grid Currents before Firing.

The general shape of the FG–17 grid current curve discussed in connection with Fig. 2 is characteristic of the

normal operation of the tube. However, both the critical grid potential and exact magnitude of the grid current before and at firing depend upon the plate potential and the temperature. In Fig. 3, six grid current curves are plotted, for two values

FIG. 3.

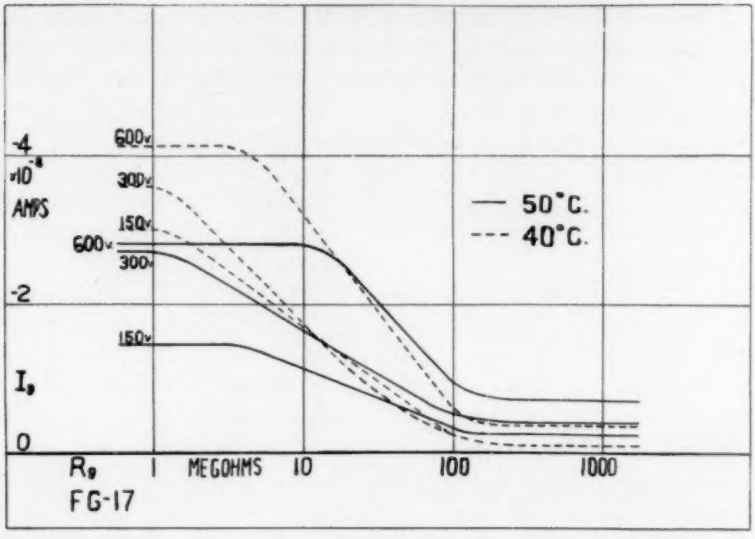


Grid current characteristics for FG–17 thyratron for different plate voltages and condensed mercury temperatures.

of condensed mercury temperature and three plate voltages. Increasing the plate voltage makes the critical grid voltage more negative and increasing the temperature also shifts the critical potential negatively. The magnitude of this shift, per degree increase in temperature, is greater at higher plate potentials.

In addition to shifting the critical potential, changes in the temperature and plate voltage also alter the shape of the grid current curve. In Fig. 4, the grid current required to fire the FG–17 is plotted against the logarithm of the grid resistance. These values of current were obtained from the curves in Fig. 3, by locating the points of tangency as described in connection with Fig. 2. With the grid resistance less than one megohm, the grid current is relatively large and

FIG. 4.



Variation of grid current at firing in FG–17 with grid resistance, for characteristics in Fig. 3.

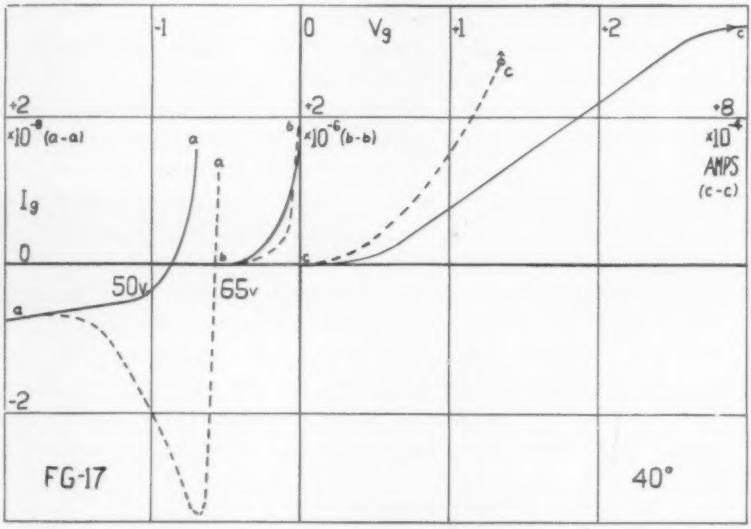
does not vary with the grid resistance, a consequence of the fact that the grid impedances at the critical potential, in Fig. 3, are negative and greater than one megohm. Between one and 100 megohms, the current varies rapidly with the grid resistance, corresponding to points of tangency which lie on the shoulder or nearly vertical parts of the grid current curves. For a resistance of 1000 megohms or higher, the currents are much smaller than for one megohm and are again practically independent of the resistance, since the point of tangency lies very near the point of minimum grid current. For a one megohm resistance the grid current at firing is greater at 40° than it is at 60°, but for 1000 megohms or higher, the reverse is true.

Anomalies at Low Plate Potentials and Temperature.

As stated before, these grid current curves are typical of the tube operating under normal conditions of temperature and plate potential. At lower plate potentials, such that the critical grid potential is nearly zero or even positive, an anomalous behavior of the grid current similar to that ob-

served by Nottingham [1] was found. With 65 volts plate potential as shown by the dotted curve in Fig. 5, the current behaves normally at large negative potentials where the grid current is mainly leakage, decreasing with decreasing voltage. At about − 1.75 volts, some electrons are able to overcome the opposing grid field and ionize the gas in the space between the grid and the plate. The arrival of these ions at the nega-

FIG. 5.



Anomalous grid current characteristics for FG–17 at low plate potentials.

tively charged grid increases the negative grid current and changes the impedance from positive to negative.

In the normal operation, the positives increase in number as the grid potential is decreased until a sheath is formed around the grid, shielding the neighboring space from the effect of the negatively charged grid and allowing the discharge to start. With a plate potential of only 65 volts, this sheath does not form at negative grid voltages, but as the grid is made more positive the rate of arrival of the electrons increases, changing the impedance from negative to positive at − 0.65 volt and actually overbalancing the ion current at − 0.55 volt, when the net grid current becomes positive.

The tube finally fires with a positive grid potential of 1.35 volts and 0.95 milliampere positive grid current.

With a plate potential of 50 volts, shown in the solid curve of Fig. 5, the impedance is positive throughout the entire range of grid voltages. Below − 1.1 volts the grid current is mainly leakage, but above that value the electron current begins and increases until at about 3 volts positive grid potential it reaches a nearly steady value of 1.3 milliamperes. This current remains at about the same value from 3 to 10 volts without the tube firing.

This type of anomaly is possible only if the grid is positive, or not more than a few tenths of a volt negative, permitting a large electron current to the grid. If the critical grid voltage for any particular plate voltage is more positive than − 0.5 of a volt, excessively large grid currents will be required to fire the tube, hence, as a measure of the plate voltage at which trouble will occur, the plate potential at which the tube fires when the grid is at zero potential may be used. If the plate potential is kept at least 5 or 10 volts higher than this "cross over" potential, the operation of the tube will be normal. As Fig. 6 shows, the cross over potential is high and varies rapidly with condensed mercury temperatures below 40° C., while above that value the change is not so rapid and the plate potential for normal operation is lower.

Optimum Operating Range of FG–17.

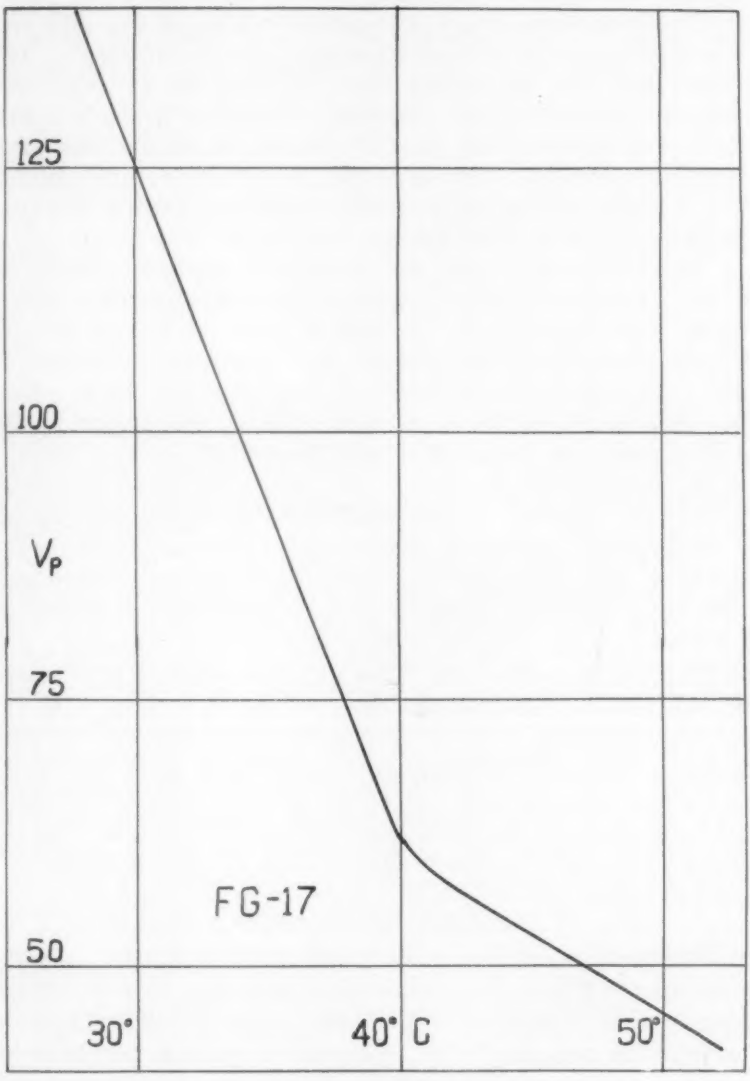
The optimum operating conditions for a thyratron used as a control tube are those which combine long life and reliability with a maximum current amplification. For the FG–17, a grid resistance above 100 megohms, a plate potential above 75 volts, and a condensed mercury temperature above 40° C. give the desired results.

CHARACTERISTICS OF FG–98.

Temperature Effects in Argon-Filled Tube.

The FG–98 differs from the FG–17 and similar tubes in that it contains argon gas in place of mercury vapor, and has a shield or screen grid in addition to the control grid. In the mercury tube, there is an equilibrium between a small amount of liquid mercury and the mercury vapor, the pressure of the

FIG. 6.



"Cross over" plate potential, or critical plate potential, for zero grid potential, in FG-17, as a function of condensed mercury temperature.

mercury vapor depending upon the temperature of the coolest part of the tube.[3] The vapor pressure varies rapidly with the temperature, and changes the characteristics of the tube considerably, as the results in the case of the FG–17 show. In a tube filled with gas rather than a vapor, the concentration does not vary appreciably over the normal operating temperature range, hence the characteristics should be free from temperature effect. An inert gas prevents contamination of the cathode, and argon is chosen because it gives a low tube drop with consequently greater efficiency.

In order to eliminate one variable, if possible, the effects of temperature on the FG–98 were first investigated. It was found that throughout the range from 4° to 50° C. the critical grid potential at various plate and screen voltages did not vary with temperature. Throughout the same range, the magnitude of the grid currents and the shape of the curves were also independent of temperature.

Effects of Shield Grid.

Livingston and Maser [5] have discussed the advantages of the four element type, which include a smaller control grid with consequently less grid emission, smaller ion and electron currents to the control grid, smaller grid capacity, and smaller leakage currents. This latter advantage is obtained by bringing the control grid lead out through the side of the tube instead of the base, thus using the glass tube wall for insulation. These advantages result in lower grid power for operation, and greater reliability. In addition, the shield grid potential varies the control characteristics, so that the same tube may be used either as a negative or positive control tube.

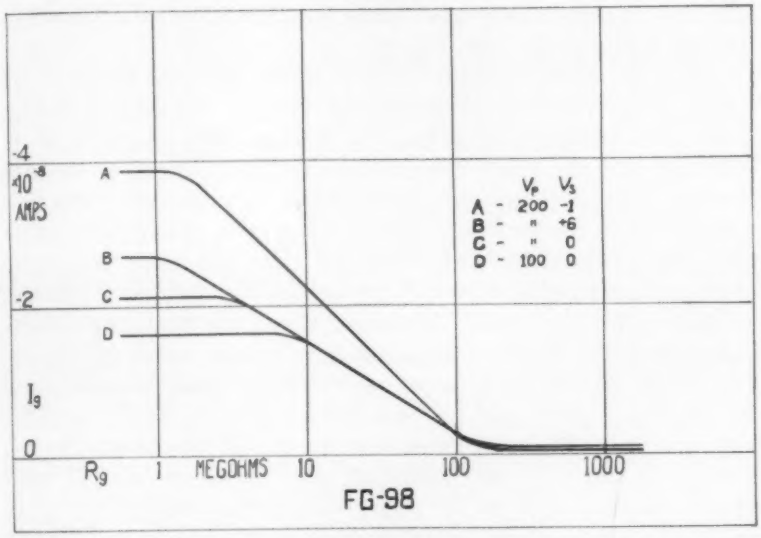
Grid Currents before Firing.

The discussion of the variation of grid current at firing with grid resistance in connection with the FG–17 applies equally well to the FG–98, since the nature of the grid current curve is the same for both. The shift in critical potential for various shield grid potentials, shown by Livingston and Maser,[5] causes a corresponding shift in the whole grid current

[5] O. W. Livingston and H. T. Maser, *Electronics*, 7, 114 (1934).

curve, but does not materially alter the shape of the curve. Hence the curves in Fig. 3 serve equally well to illustrate the shape of those for the FG–98, although the latter has slightly lower grid currents. In Fig. 7, the values of grid

FIG. 7.



Variation of grid current at firing with grid resistance in FG–98 thyratron, for different plate and shield grid potentials.

current at firing for various grid resistances have been taken from the tangents to the actual grid current curves of the FG–98. This set of curves is also similar in shape to those for the FG–17 in Fig. 4. In both cases above 100 megohms the grid currents are small and practically constant, but in the FG–98 they are two to five times smaller than in the FG–17. In the four element tube, with high grid resistances the shield grid has very little effect, but with low values a shield potential of zero gives the lowest grid current

Anomalies at Low Plate Potentials.

At low plate potentials, anomalies are found which are closely tied up with the shield grid potential. With the shield grid at zero and the plate at 55 volts, the grid current

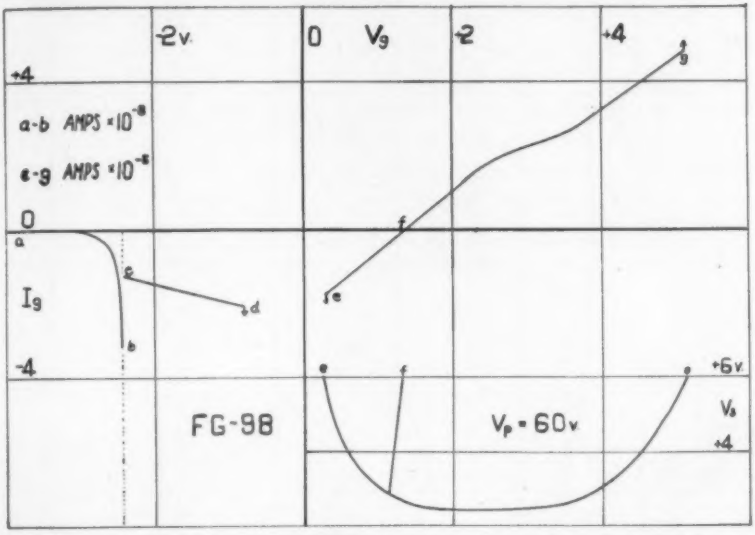
curve has the normal shape, while at a plate potential of 50 volts, the grid current at first follows the normal curve, but soon reverses, without the tube firing. At 1.40 volts positive, the increasing electron current begins to overbalance the positive ion current, and from there on to 7.50 volts, where the tube fires, the electron current rapidly increases. This behavior is essentially the same as that described in connection with the FG–17, Fig. 5.

With the shield grid 6 volts positive and the plate at 60 volts, a very different phenomenon occurs. Referring to Fig. 8, the grid current curve has the normal shape from *a* to *b*. Although at *b* the grid current increases abruptly to *c*, roughly 30 times its previous value (note the change in scale), the full cathode to plate discharge does not begin at this point, but a faint glow in the neighborhood of the plate indicates that some electrons are passing through the field of the grid and causing excitation in the space between the grid and the plate. There is not sufficient ionization here to start the main arc, but as the grid is made more positive this glow remains and the negative grid current increases approximately linearly with voltage, until the tube fires at *d*. If the plate circuit is opened, and the grid potential made positive until it falls on the second section of the grid current curve, *e–f–g* in Fig. 8, the plate circuit may be closed and the tube will not fire. The grid potential may now be made either more negative or more positive, and the tube will fire in the former case at *e*, and in the latter case at *g*. The faint glow indicating excitation is present between the grid and the plate throughout this range. At the lower right of Fig. 8, these firing points *e* and *g*, as well as the voltage for zero current *f*, are plotted as a function of shield grid potential. As the shield voltage decreases, the firing points approach each other and coincide at a shield potential of about 2.40 volts. The phenomenon does not occur when the shield grid potential is more negative than + 2.40 volts.

Optimum Operating Range of FG–98.

The optimum plate potential range of the FG–98 is from 75 to 180 volts, the grid resistance should be above 100 megohms, and the shield grid potential may range from − 1

FIG. 8.



Anomalous grid current behavior in FG–98 for low plate potential and shield grid 6 volts positive. Lower right hand curve shows limits of anomalous behavior as a function of shield potential.

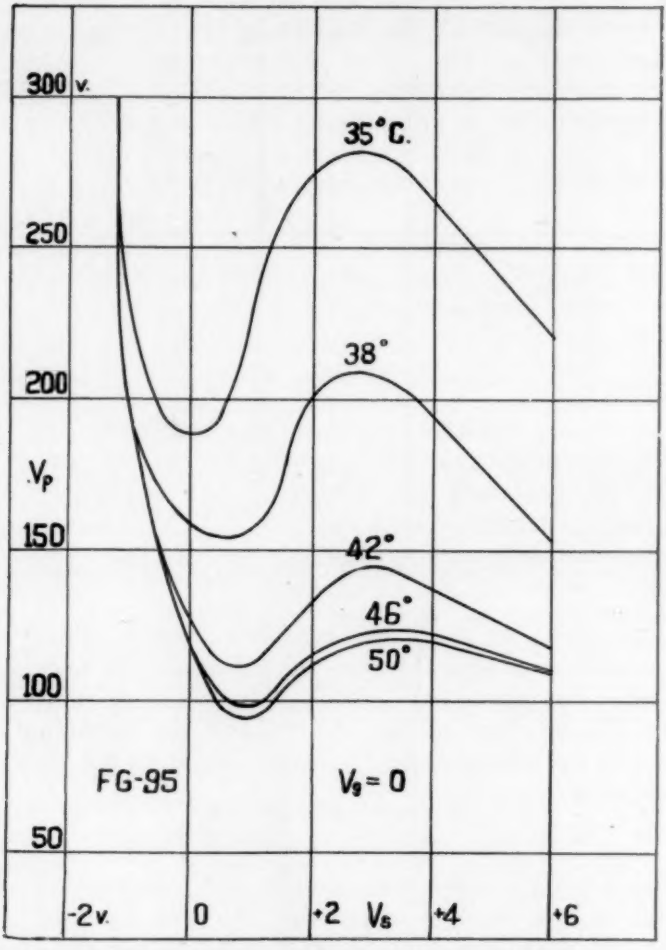
to + 6 volts. If the grid resistance must be lower than 100 megohms, a zero shield potential gives the lowest grid current. The upper limit of the plate voltage is much lower in the FG–98 than in the FG–17, but the minimum grid current in the former is slightly lower and does not vary with temperature.

CHARACTERISTICS OF FG–95.

Temperature Limitations on Shield and Plate Potentials.

The FG–95 has the same double grid construction as the FG–98, but is slightly larger and contains mercury vapor whose concentration changes with temperature causing the characteristics to vary accordingly. In the FG–95 the cross over potential, defined as the plate potential at which the tube fires with the control grid at zero, varies not only with the temperature as in the FG–17 (Fig. 6), but also with the shield grid potential. Referring to Fig. 9, the best shield grid potential at which to operate is that which makes the cross over potential a minimum, but this shield potential is not critical, so that for the usual operating temperatures, a

FIG. 9.



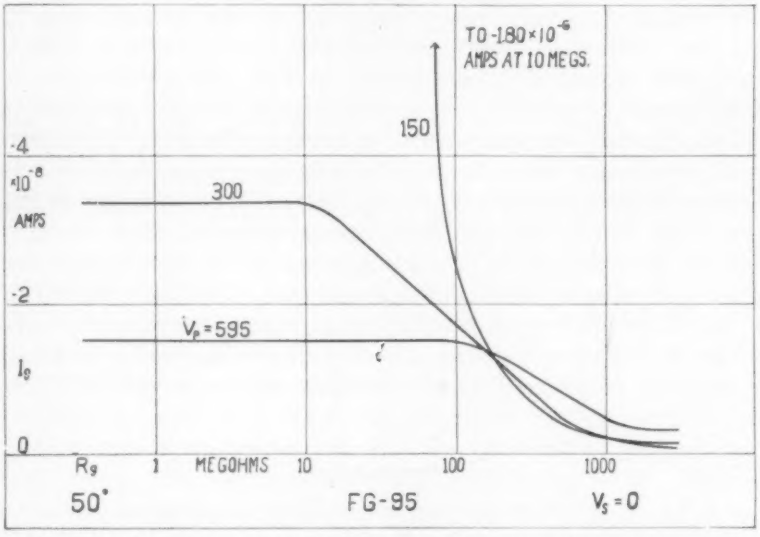
"Cross over" plate potential in FG–95 thyratron, as a function of shield grid potential and condensed mercury temperature.

value between zero and 2 volts positive is satisfactory. Since the tube should not be operated below 40 degrees condensed mercury temperature, higher positive shield potentials may be used without raising the cross over potentials appreciably, but a negative screen potential of a volt or more causes a prohibitive rise in the cross over potential.

Grid Currents before Firing.

The general shape of the grid current curves for the FG–95 is also similar to those for the FG–17 shown in Fig. 3. The shift in critical potential with shield grid given by Livingston and Maser [5] agreed satisfactorily with the values found. The grid currents at firing for various grid resistances have been found by the point of tangency method described above, for the particular case of zero shield grid potential, since Fig. 9 shows that to be the most useful potential. These values plotted in Fig. 10, although similar in shape to those

FIG. 10.



Variation of grid current at firing in FG–95 with grid resistance for different plate potentials.

for the FG–17 and FG–98, differ considerably in magnitude. For 150 volts plate potential and a grid resistance of 10 megohms or less, the grid current at firing is very large, for the tube is being operated too close to that part of the range which shows the anomalous behavior discussed in connection with the FG–17, but with a grid resistance of 1000 megohms or greater, the grid currents are reasonably small. For 300 and 595 volts plate potential, the behavior is similar to that of the FG–17 under the same circumstances, although in the

case of the FG–95 a grid resistance of 1000 megohms, instead of 100, is required to obtain the minimum grid current.

Shift in Critical Potential with Past History.

The above measurements of the grid currents in this particular FG–95 disclosed a shift in the critical grid potential which was not caused by any change of plate, shield or filament potential or of temperature, but which was dependent only upon the recent history of the tube. Further investigation showed that it was apparently caused by the evaporation of active material from the cathode to the grid, with subsequent removal by sputtering during a conducting period. The changing amounts of material on the grid altered its contact potential, hence an apparent shift in the critical potential, which amounted to 0.5 of a volt under certain conditions.

In all the tests discussed only one tube of a particular type was used, hence the tests in no sense represent average characteristics. In the particular case of the shifting critical potential in the FG–95, it is not possible to state whether this is a characteristic of all FG–95's, only a few, or whether this one tube was actually defective. The fact that this tube was made for commercial work, however, makes it worth while to mention that such a phenomenon may occur, so that it may be recognized as the possible source of difficulties in other tubes, either of the FG–95 or another type.

Optimum Operating Range of FG–95.

Neglecting the fact that the shift in the critical potential found in this FG–95 makes it rather unsuitable as a low grid current control tube, it is possible to predict the optimum operating range for an FG–95 which has a reliable critical potential. The condensed mercury temperature should be above 40° C., the shield potential between zero and 2 volts positive, and the plate potential above 160 volts. The grid resistance must be above 1000 megohms, ten times higher than either the FG–17 or FG–98 require to give the minimum grid current. Although this minimum value lies between those of the FG–17 and FG–98, the five times greater anode current rating of the FG–95 makes its maximum current amplification superior to that of the others.

CONCLUSION.

The operating characteristics of thyratrons may be divided into two classes, anomalous and normal. The data showing the "cross over" potential as a function of the temperature in the FG–17, and of both the temperature and shield potential in the FG–95, serves to give the boundary between the two. Although temperature has no effect within the usual operating range of the FG–98, anomalies occur below 75 volts on the plate, particularly if the shield is positive. Since there may be applications, especially in A.C. circuits, where it is necessary to operate the tubes within the range where anomalies occur, their nature has been shown in some detail, in order that they may be better understood and allowances made.

In order to use the thyratron most effectively, it is important not only to avoid anomalous behavior, but to understand more fully the normal behavior. Too much emphasis cannot be placed upon the significance of the magnitude and sign of the grid impedance. In the three tubes investigated here, the grid impedance under normal operating conditions was negative near and at the critical potential. Here, the current sensitivity is not proportional to the external grid resistance, but is given by equation (3). Therefore, as Figs. 4, 7 and 10 show, for high current sensitivity it is not only possible [6] to use grid resistances of 100 to 1000 megohms, it is essential.

The author wishes to take this opportunity to thank Professor W. B. Nottingham, who supervised this work, for his kind assistance and helpful suggestions, and Mr. W. R. Perret and various members of the Physics Department of the Massachusetts Institute of Technology for their aid on numerous occasions.

[6] A. W. Hull, *Physics*, 4, 66 (1933). In this paper Dr. Hull gives curves of the grid currents at starting in the FG–95 and FG–98, and states that "a resistance of 1000 megohms in series with the grid does not interfere with reliable starting." Subsequent correspondence with Dr. Hull has revealed that he actually used 1000 megohms in series with the grid to obtain these grid currents. When this fact is taken into account, the values shown in Figs. 7 and 10 agree satisfactorily with those given by Dr. Hull.

TECHNICAL INFORMATION.

G. E. Co. Code Number	FG–17.	FG–95.	FG–98.
Number of Electrodes	3	4	4
Cathode			
Volts	2.5	5.0	2.5
Amperes	5.0	4.5	5.0
Type	Coated Fil.	Ind. Heated	Coated Fil.
Heating Time	5 sec.	5 min.	5 sec.
Max. Peak Anode Volts			
Inverse	2500	1000	180
Forward	2500	1000	180
Max. Anode Cur. (amperes)			
Instantaneous	2.0	15	2.0
Average	0.5	2.5	0.5
Max. Shield Grid Cur.			
Instantaneous		1.0	0.25
Average		0.25	0.05
Max. Control Grid Cur.			
Instantaneous	0.25	1.0	0.25
Average	0.05	0.25	0.05
Tube Voltage Drop			
Maximum	24	24	24
Minimum	10	10	10
Gas	Mercury Vapor		Argon
Temperature Limits (° C.)	20 to 50	20 to 50	− 20 to 50
Deionization Time (microseconds)	1000	1000	1000
Type of Cooling	Air	Air	Air
Source of Information	GET–428A	GET–545	GET–546

SOME NEW AND UNIQUE APPARATUS FOR BIOCHEMICAL STUDY.

BY

ELLICE McDONALD, Director,

Biochemical Research Foundation of The Franklin Institute.

In biochemical and biological study, one great difficulty is the large number of variables which are present in vital systems. Life is a chemical phenomenon dependent upon physico-chemical structure, but cellular organization and arrangement play a great part in influencing biochemical estimations. It is seldom possible to remove cells from their habitat without profoundly altering their reactions.

In the past, the main tool for cellular study has been the microscope; however, this type of study as developed by the histologist, pathologist and cytologist is mainly observational and not experimental. There is a definite limit to observational study of cells since it does not explain *mechanism* of cellular action, the most important present phase of biochemical study. Observation of cellular material by the microscope is largely a study of end results and seldom throws light on the mechanism of intermediate cellular reactions, particularly in regard to cell function as opposed to structure.

Animal experimentation, a useful tool, also has large numbers of variables, even though these are reduced as much as possible by the use of standardized strains and uniform conditions of feeding, etc. This type of study requires much time and when the final results are obtained their interpretation is often difficult on account of the few available criteria.

The study of analogous systems is a useful means upon which to work out methods of application to cellular biochemical study. As examples of this may be cited the study of the metabolism of yeast to throw light on methods for the chemical study of animal cells, and the study of the irradiation of plant root tips in its application to research upon the effects of radiation upon animal cells. But after all, it should be

remembered that analogous systems are only analogous, and it is not always possible to carry the experimental results obtained upon these systems over to the real material to be studied. It is possible to pursue the study of analogous systems too far without realizing that sometimes it is necessary to study the actual material about which experimental facts are sought. It is not good to run too fast upon the wrong road.

In biochemical study, the need is for methods to give quantitative and statistical results, and to reduce as much as possible the variables such as occur in vital systems. The essential pre-occupation of the biologist should be to remove the feeling of being intolerably hampered by irrelevant necessities, and a powerful desire for disentanglement of the obscuring factors in experimentation.

To obtain statistical and quantitative results in a biological system, one important and useful measure is to correlate that system to an exact experimental method and, by this means, obtain quantitative results, at least in one direction. This means the application of the exact sciences, physics and chemistry, to biological experimentation. This effort is hampered by the sensitiveness of living material with respect to its function, and by the fact that very minute amounts of various substances often exert profound influences in vital reactions. This requires the elaboration of new micro-methods.

In our laboratories, there is in use considerable unique apparatus, some adapted, some developed by us. Descriptions of these tools for research, in their applications to biochemical study, may be of interest to others, and they are given here for that reason. The detailed descriptions are written by the workers themselves, although the entire group has coöperated in the effort of construction and adaptation. The descriptions have been done by Doctors Allen, Schroeder, Elliott, Bancroft, Weil, Sanigar, Magill, Munro, Woodward, and Russell. Particular credit should be given to Dr. A. J. Allen for his ingenious and skilful adaptability.

I. THE APPLICATION OF ABSORPTION SPECTRA, DETERMINED BY THE ECHELON CELLS, TO CERTAIN BIOCHEMICAL PROBLEMS.

The availability of new tools often determines the scope of new researches, and often a plan of research is arranged around a new scientific tool. This was the result with the advent of the Notched Echelon Cells, originally a loan to our laboratories by Mr. Twyman of Hilger & Co.

It is possible by means of these cells to study any substances which can be put into solution and which have absorption spectra in the ultra-violet. They have been used in these laboratories for the study of the blood of cancer patients in its various phases, but the method is equally applicable to the study of blood or other biological fluids in many other diseases. It is a new biological tool borrowed from physics, and for that reason is described here so that it may be of use to other workers in the biochemical field.

Introduction.

Absorption spectra are obtained when a substance capable of absorbing light, usually a chemical compound in solution, is placed between the source of light and the slit of a spectrograph. The absorption of light may be general from a given point to the end of the spectrum, i.e., continuous absorption, or may occur only in certain regions, i.e., selective absorption, producing absorption bands. Such absorption bands, occurring in definite regions of the spectrum, can be used to characterize the substance producing them, although other substances may show absorption over the same region.[1]

In order to obtain comparable results for different substances, the absorption of light of a given wave-length is expressed as an extinction coefficient which is defined as the reciprocal of the thickness of solution required to reduce the intensity of the incident light to one-tenth its original value. This can be shown to be equal to the logarithm to the base ten of the reciprocal of the ratio in which the light is reduced on passing through unit layer of the absorbing medium. Since it is not convenient to determine the extinction coefficient by

[1] An interesting survey of spectroscopy and its applications is given in "Spectroscopy in Science and Industry," by S. Judd Lewis. Blackie & Son, Ltd. 1933, p. 94.

direct measurement, it is ascertained by measuring the intensity of the transmitted light (I) in terms of the intensity of the incident light (I_0), using a suitable thickness, t, of the solution, calculating the extinction coefficient, E, from the expression:

$$E = -(1/t) \log (I/I_0).$$

Thus, to obtain the extinction coefficient for a given solution, it is necessary to be able to compare the intensity of the incident light and the transmitted light. The most convenient way to do this is to divide the light from the source into two divergent beams, one of which passes through the solution whose absorption is being measured, while the other passes through the solvent used for the solution being studied. The two beams are finally brought together in front of the slit of the spectrograph in such a manner that the resulting pair of spectra are contiguous on the photographic plate on which they are recorded. If, now, in the path of the beam which does not pass through the solution, is placed a device, such as an adjustable rotating sector, whereby the intensity of the light can be diminished to a known fraction of the original, the two spectra can be used to determine the extinction coefficient of the solution. This is possible since the light of that wave-length which is equally absorbed by travelling either path will produce an image of equal density in the photographs of the two spectra. Thus, by determining those wave-lengths where the two spectra show equal density, the extinction coefficient can be obtained, since the thickness (t) of the solution can be measured, and the ratio I/I_0 is known from the sector setting.

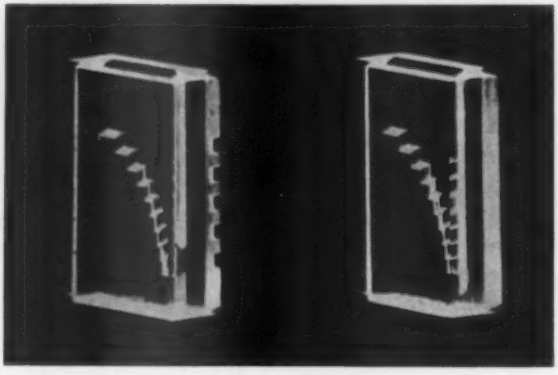
A given solution of an absorbing substance will show one or more absorption bands produced by the absorption of light of wave-lengths between the extremities of the bands. Dilution of the solution allows more light to be transmitted, i.e., narrows the absorption bands, so that, by successive dilution, the extinction coefficients for light of wave-lengths which were originally entirely absorbed can be obtained. By plotting wave-lengths (or frequencies) as abscissæ and extinction coefficients as ordinates, an absorption curve is obtained, showing the fraction of light of each wave-length which is absorbed by a layer one centimetre in thickness of the solution under examination.

The Echelon Cells.

The principle of the method employed is given in a paper by Twyman, Spencer, and Harvey [2] and its more recent developments in a paper by Twyman.[3]

Since, with a given substance, a decrease in the thickness of the layer used is equivalent to a dilution of the solution, extinction coefficients can be studied by varying the thickness of the layer used as well as by the use of the same thickness of solutions of differing concentrations. The purpose of the Echelon Cells is to decrease the work involved in making a separate exposure for each different thickness or different concentration used. This is achieved by having the cavity holding the solution irregularly shaped by means of steps so that the absorption of a number of different thicknesses, between which there exists a known ratio, of the same solution can be obtained simultaneously. A second cell, similar to the first, is required to give the necessary comparison spectra.

FIG. I.



The Echelon Cells.

The appearance of the cells is shown in the photograph (Fig. I). The "notched cell" contains the solution under examination and the un-notched (or "plain") cell, similar to the notched cell except for the notches, contains the solvent.

[2] Twyman, Spencer, and Harvey, *Trans. Opt. Soc.*, **33**, 1931–32.
[3] Twyman, F., *Proc. Phys. Soc.*, **45**, 1 (1933).

One edge of the notched cell is serrated so that the teeth and the spaces are of equal width and in such positions that any given tooth or notch matches one-half of one internal step and one-half of the step immediately below it. Due to these teeth and notches the spectrograph alternately receives light which has passed through the notched cell and been reflected into the spectrograph slit from the teeth of the notched edge, and light which has passed through the plain cell, been diminished by means of a rotating sector, and has passed through the spaces in the serrated edge. Since the cells have ten steps, giving 0.1 to 1.0 cm. of solution thickness, ten pairs of spectra, each consisting of an absorption spectrum and its corresponding comparison spectrum, are photographed in one exposure. By adjustment of the sector aperture, extinction coefficients from 0.155 to 16.0 can be measured.

The Echelon Cells are made of fused quartz for work in the ultraviolet region of the spectrum and, for the present work, are used (in a special holder supplied with the cells) in conjunction with an all-quartz, Bausch and Lomb, Model E, spectrograph. Eastman Kodak 33, 4 × 10 inch plates are employed, the exposure required being of the order of 15 seconds for the low extinction coefficients and 4 minutes for an extinction coefficient of 15.0 with the hydrogen arc at present in use.

Plate-reading Apparatus.

As indicated previously, reading the plates consists of examining each pair of spectra for those points where the densities of the two spectra are identical. At such wave-lengths the effective density of the column of solution is equal to the effective density of the sector. The adjustable rotating sector is graduated so that the extinction coefficient can be expressed by the equation: $E = D/t$, where D is the effective density of the sector. Since the thickness of solution corresponding to each step is known, the extinction coefficients for a given sector density become known, so that it is only necessary to record the wave-lengths of the match-points corresponding to each thickness of solution to have the data required for the plotting of the absorption curve.

After trying several methods for examining the plates (viewing in front of a light, printing the plate onto photo-

graphic paper, projecting an image of the plate horizontally) it was found most satisfactory to project the plate vertically onto a white paper on a table in front of the observer. The camera employed is an Eastman Kodak Compur camera (Xenar $F = 13.5$ cms. lens), the camera lens being at a convenient distance of 33.5 inches above the observer's table so that the plate can be inserted in the camera and moved without trouble. An ordinary 60-watt, frosted-bulb, electric lamp, situated about 9 inches above the plate, is employed as a light source, the light passing through a pair of short focal length projector-lantern condensers before passing through the plate and camera. The magnification of five, which is employed, has been found very satisfactory.

In determining the match point for a given pair of spectra it has been found most advantageous to cover the image of the remainder of the plate with dull, black paper leaving only the required pair of spectra, or the necessary portion of it, exposed to view. In this manner, the eye of the observer is not distracted by the contrasts on the remainder of the plate, nor is his judgment of the match-point under consideration influenced by those marked previously or those following which are unintentionally anticipated through being in the field of vision.

The reference wave-length scale may be either printed on the plate or, to increase the number of exposures which can be made on a plate, may be omitted from the plate, in which case the scale, printed on a thin strip of glass, can be attached to the plate by means of adhesive tape in such manner that the proper wave-length corresponds to some convenient reference line of known wave-length. When using a continuous arc, the almost entire absence of reference lines makes it necessary to mark the emulsion of the plate with a fine point at accurately measured distances from one of the few reference lines available. This is done by placing an accurately pierced celluloid scale, which fits the plate, onto the plate so that the proper hole appears over the end of the reference line, and then marking with a fine point through the other holes in the scale. These marks correspond to definite, convenient wave-lengths and, being plainly visible when the plate is projected, are used as reference marks. A series of cardboard scales,

identical with the projected wave-length scale and covering the whole range of the plate, is then used to establish the wave-lengths of the match-points.

The field of view is approximately 16 × 6 inches, and the plate is inserted in the camera so that at least one reference point is in the field of vision. The position of each match-point is marked by a cross on the sheet of white paper, attached by spring clips to the observer's table, and when all the match-points within the field of vision have been marked the corresponding wave-lengths are recorded along with the corresponding extinction coefficients. The absorption curve is then obtained by plotting extinction coefficients against wave-lengths.

The Hydrogen Discharge Tube.

Spectra obtained from a spark between metal electrodes contain lines across the spectra, more or less numerous and more or less bunched together, depending on the metal used as electrodes. The match-points are easier to detect with a continuous spectrum than with a continuous background on which lines are superimposed, and are hard to detect with accuracy when they occur in a region which is crowded with intense lines. Of the metal electrodes used for the spark spectra, twisted Chromel A wire was found to be the most suitable since it gave fairly regular distribution of lines of fairly even density.

The source of ultraviolet light finally adopted is the water-cooled hydrogen discharge tube with quartz window, shown in Fig. I *a*.[4]

The discharge occurs in hydrogen having about 8 mm. pressure, the resultant light being brought, by means of a quartz lens, to a focus in the position necessary for the image to act as a point source of light for the spectrograph. The continuous spectra obtained make possible the locating of match-points without the eye-strain resulting from the contrast between lines and gaps of the ordinary metal spark spectrum. The complete assembly of the apparatus for taking the spectrograms is shown in Fig. I *b*.

[4] An excellent design of a hydrogen arc, together with absorption technique, is described by Chatelet. "Spectres d'Absorption Visibles et Ultra-violets des Solutions." Actualités Scientifiques et Industrielles, No. 54. (Hermann et Cie. Paris, 1933, p. 24.)

FIG. I *a*.

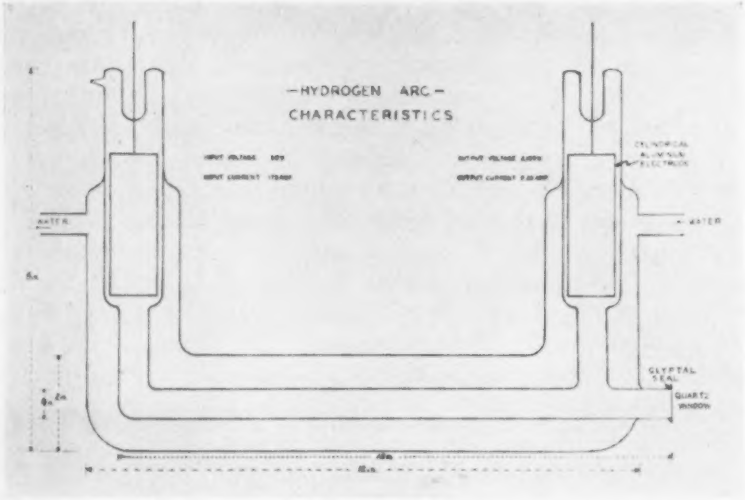
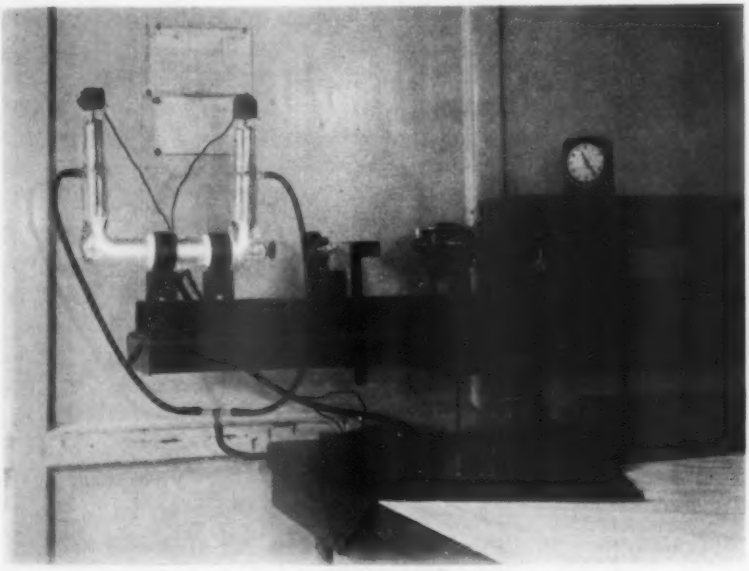


Diagram of hydrogen arc.

FIG. I *b*.



The spectrographic assembly, showing the hydrogen discharge tube.

Biological Applications of the Method.

Whilst the method is applicable to the study of the absorption spectrum of any solution, biological or not, the absorption spectra, obtained as described above, are being used at present to determine the differences in absorption between partially precipitated cancer and normal blood plasma and serum. The plasma (and serum) proteins, as do certain other body fluids such as saliva, pericardial fluid, urine and bile, have a pronounced absorption band having a peak at approximately 2800 A° and a minimum at approximately 2400 A°. The method is also being used to study the absorption curves of amino acids and polypeptides, as well as the effects of x-rays on these substances, the latter effects being followed by observing the changes in their absorption spectra.

II. THE ALL-QUARTZ MICROSCOPE AND MONOCHROMATOR.

A microscope with an all-quartz optical system which was designed by Doctors Köhler and Von Rohr of the Carl Zeiss Scientific Staff constitutes a useful apparatus for studying a number of interesting biological problems. Its original purpose was to attain a higher resolving power by using the shorter wave-lengths to which the glass optical systems are opaque. It has, however, other important uses. Such a microscope equipped with a quartz monochromator and a suitable source of ultraviolet radiation enables one not only to obtain photomicrographs of high resolution but also to study the absorption of various wave-lengths of visible and ultraviolet irradiation by the various parts of microorganisms. That is, it enables one to determine roughly the absorption spectrum of microscopic parts. It can be used to study the effects of these radiations on the organisms while they are under the microscope and to correlate the radiation effects with the absorption.

The selective absorption of the microscopic parts produces a "staining" effect which enables a better study of the structure of living or unstained organisms.

The apparatus consists essentially of a regular Zeiss microscope stand to which has been fitted a set of three all-quartz objectives and four eyepieces. A focusing eyepiece which contains a small fluorescent screen supplements the

other eyepieces and provides a visual method of roughly focusing any wave-length of the invisible ultraviolet radiations. The photographic apparatus is the same as for visual radiation photography. Ultraviolet radiation, from any convenient source, is made monochromatic with a quartz monochromator and is directed into the condenser of the microscope by a totally reflecting quartz prism. Instead of a cadmium or magnesium spark a small mercury arc serves as a source of ultraviolet radiation. Its advantage is that it has a number of well-separated lines throughout the visible and ultraviolet spectrum regions which enables the taking of a series of photomicrographs with these lines. To facilitate selecting the desired wave-length a pointer and wave-length scale may be attached to the monochromator part of the apparatus which, when once calibrated, allows any wave-length to be quickly directed into the condenser of the microscope. The lens system is not achromatic, consequently it is necessary that the monochromator lens as well as those of the microscope be focused for each wave-length setting. A fluorescent screen placed on the diaphragm of the condenser enables the focusing of the monochromator. To determine the proper microscope setting for each wave-length it is convenient to plot a curve with wave-lengths as abscissæ and readings of the fine adjustment focusing screw as ordinates. Figure II is a photograph of the assembled apparatus.[5]

The uses of this apparatus may be summarized as follows:

1. The all-quartz monochromator and microscope can be used as a micro absorption spectrograph to determine roughly the visible and ultraviolet absorption spectra of microscopic biological parts.

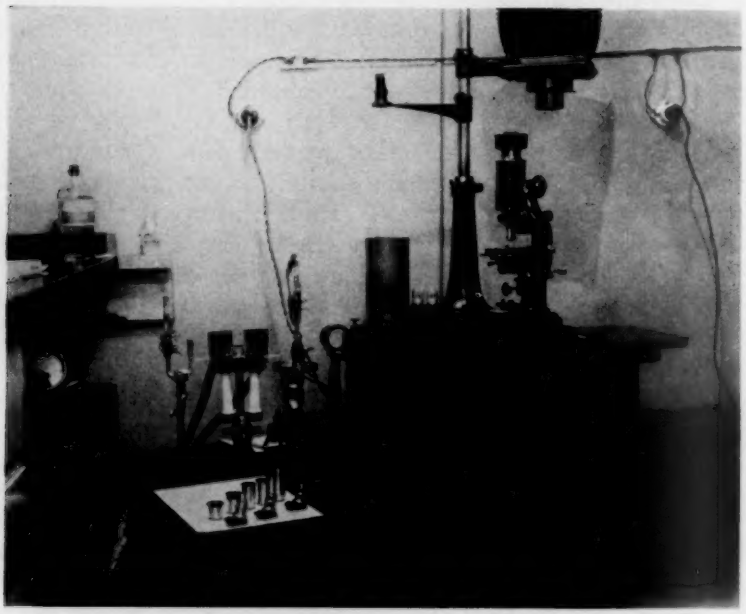
2. It can be used as an instrument for observing the irradiation effects of various wave-lengths of visible and ultraviolet radiation while the organisms are being irradiated.

3. A correlation between absorption and irradiation effects can be made.

4. It provides a method of obtaining more than one picture

[5] For a bibliography and a more detailed description of the apparatus see Allen, A. J., Franklin, R. and McDonald, Ellice, JOURN. FRANKLIN INST., 218, 701 (1934).

FIG. II.



The all-quartz microscope and monochromator.

of the same piece of tissue thus enabling a more thorough study of the tissue structure.

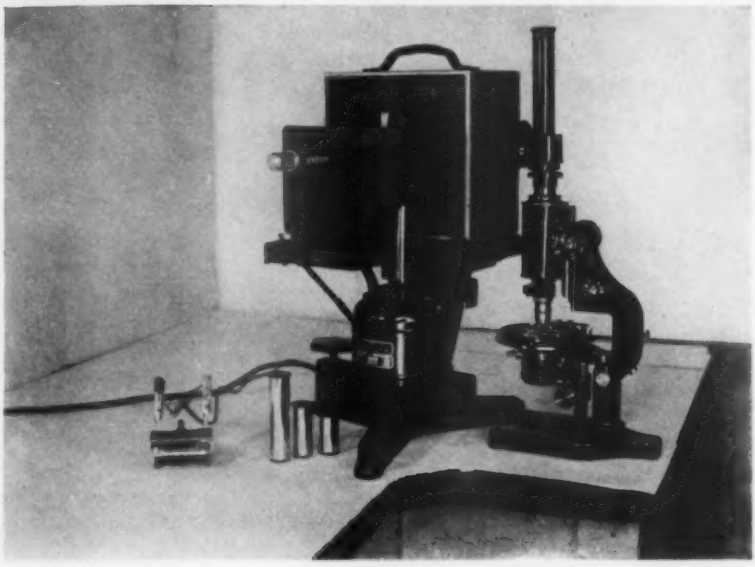
5. Living or unfixed tissue can be better studied due to the staining effect produced by the selective absorption of the shorter wave-lengths. This also enables the elimination of the changes due to the fixing and staining process.

III. A MOVIE CAMERA USING 16 MM. FILM ADAPTED TO THE ALL-QUARTZ MICROSCOPE.

An ordinary moving picture camera using 16 mm. film, adapted to take photomicrographs of living cells, is a valuable scientific apparatus for certain biological problems. In our laboratory we have an apparatus built by Bausch and Lomb with which we have taken several moving pictures showing the effects of ultraviolet radiation on a number of species of protozoa. The apparatus is illustrated in Fig. III.

The apparatus consists of an ordinary Ciné-Kodak, Model

FIG. III.



16 mm. movie camera adapted to all-quartz microscope.

A, moving picture camera to which has been fitted an observation eyepiece instead of the regular lens. One-tenth of the light passes to the observer's eye while nine-tenths fall on the sensitive film. Thus one can see exactly what is being photographed. The camera is turned by an electric motor and a gear-shifting arrangement gives a wide variety of speeds. By turning the camera at very slow speeds and then showing the film at normal speed, several days' growth of cells can be shown in a few minutes. The action of ultraviolet radiation is so rapid that the pictures are usually taken at normal speed.

Any standard microscope can be used in conjunction with the observation eyepiece and camera. Special eyepieces giving different magnifications are supplied. Precautions for obtaining good photomicrographs are the same as those for the regular photomicrographic technique. The camera has been adapted to the quartz microscope and monochromator.

To show the lethal effects of ultraviolet radiation on protozoa it is necessary to have a quartz condenser, and the

organisms must be mounted on a quartz slide. A Leitz quartz darkfield cell with a glass coverslip is admirably suited to this purpose. Glass optics may be used in the microscope. A small constricted high-pressure mercury arc of special design is mounted just below the quartz condenser thus avoiding the use of a quartz totally reflecting prism, as the ordinary glass reflecting mirror cannot be used.

To get pictures as the organisms are ordinarily seen a thick piece of green-blue glass is interposed between the arc and the quartz condenser, thus preventing any lethal ultraviolet radiation from reaching the organisms. To apply the radiation, it is only necessary to remove the glass and the lethal effects are observed. The light is sufficiently intense that ordinary positive 16 mm. film can be used, which is quite inexpensive.

IV. A PHOTOELECTRIC QUANTUM COUNTER.

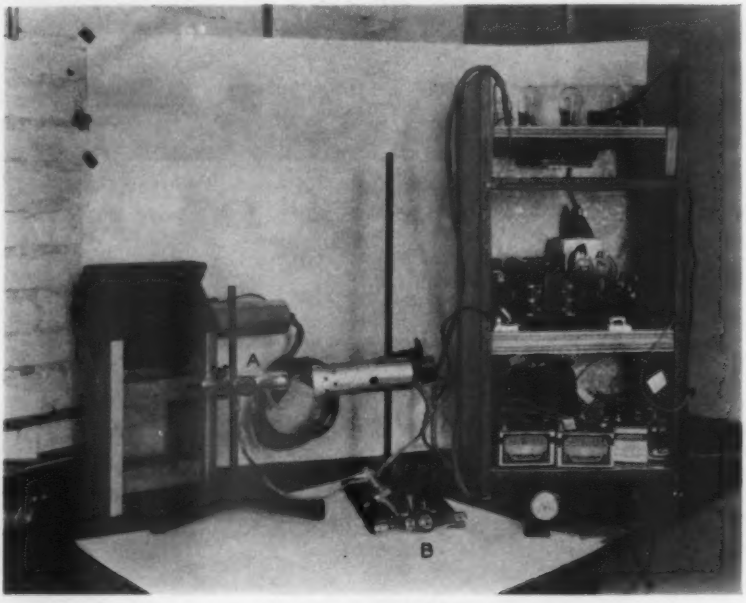
The photoelectric quantum counter provides an instrument which is extremely sensitive to radiant energy.[6] It is essentially a Geiger-Mueller counter to which has been adapted photoelectric features. By slightly modifying the counter window it can be made to count alpha-rays, beta-rays, gamma-rays, x-rays, and cosmic-rays, i.e., any ionizing rays.

The apparatus is illustrated in Fig. IV. The quantum counter tubes *A* and *B* are essentially the same as those described by Locher. A fine platinum wire is stretched in the center of a copper cylinder 3.5 cm. long and 2 cm. in diameter, a strip 1 cm. wide having been cut from the cylinder wall parallel to the axis. This is securely mounted in a Pyrex tube onto which has been sealed a quartz window. The copper cylinder has a photoelectric threshold at 2500 A°, i.e., the sensitivity is low to wave-lengths longer than this value and increases rapidly for shorter wave-lengths. By electroplating the copper tube with different metals the threshold can be changed. For example, the threshold for chromium is about 2900 A°.

The counter tube must be supplied with a constant source of potential, the magnitude of the potential depending on the

[6] Locher, G. L., *Physical Rev.*, **42**, 525 (1932).

FIG. IV.



A photoelectric quantum counter for detecting ultraviolet radiations of low intensity. *A* and *B*, quantum counter tubes.

physical characteristics of the tube and on the degree of vacuum established. A Street and Johnson [7] voltage control apparatus was used to supply a constant source of potential. The amplification system is essentially the same as that described by Johnson and Street.[8] The apparatus was built at the Bartol Research Foundation and considerable help was received from various members of the staff, especially from Dr. E. C. Stevenson.

The apparatus was used in our laboratory to detect fluorescent ultraviolet radiation from solutions excited by cathode rays. We were interested in detecting the amount of radiation of wave-lengths shorter than 2900 A°, and the chromium counter was admirably suited to this purpose. To prevent x-ray quanta from affecting the counting rate it was

[7] Street, J. C. and Johnson, T. H., JOURN. FRANKLIN INST., 214, 155 (1932).
[8] Johnson, T. H. and Street, J. C., JOURN. FRANKLIN INST., 215, 239 (1933).

necessary to shield the counter tube carefully in a lead box. By using a right-angle lead tube and a totally reflecting quartz prism, a periscope arrangement was made which would reflect the ultraviolet radiation into the counter, but not the x-rays.

The apparatus can be used in any problem involving the detection or measurement of very low intensities of radiation. For instance, the ultraviolet radiation emitted from an ordinary safety match burning at a distance of forty feet is readily detected. A milligram of radium is easily detected at a distance of several feet.

V. THE WARBURG MANOMETRIC APPARATUS.

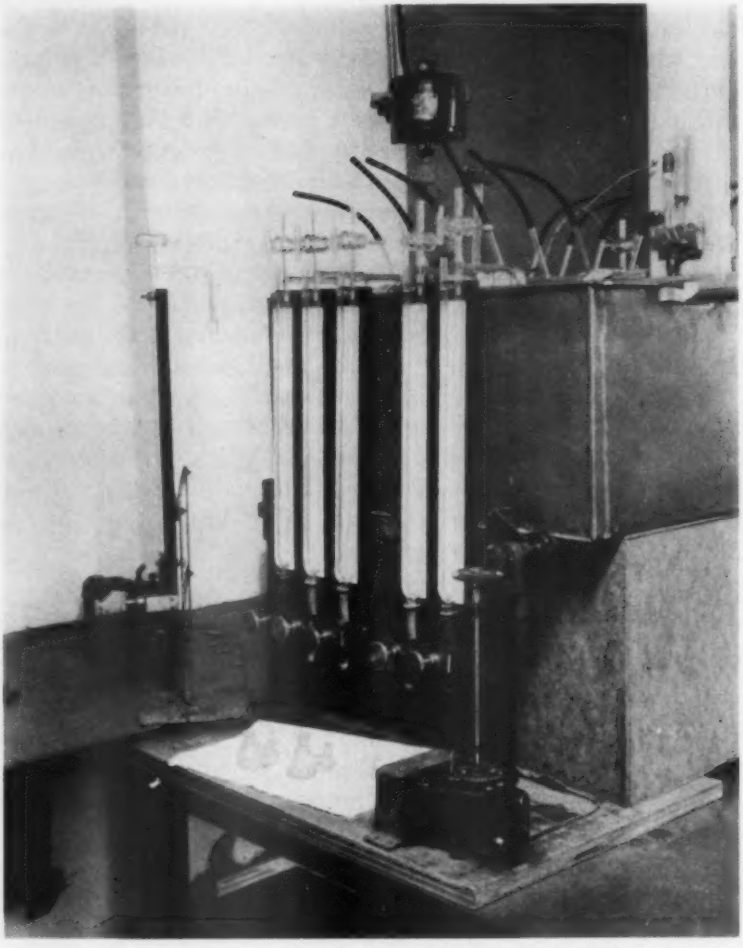
The manometric technique, as developed in modern times by Barcroft, Warburg. Dixon, Keilin, and others, has the advantage that the metabolism and enzyme reactions of slices of living tissue may be studied in glass by exact chemical methods. In many cases, results are quickly achieved which could not be obtained by years of animal experimentation. Slices of living tissue may be studied in these manometers in a state differing but little from that in which they exist in the animal body. Constant and reproducible results may be obtained with ease.

By these methods, much information may be obtained on the intermediate chemical mechanism of the various cellular reactions. Likewise, alterations produced by insertion of new compounds, dyes, hormones, vitamins, etc., can easily be observed. These studies may well open up a new phase in the science of pharmacology, as well as extend our knowledge along the lines of physiology and biochemistry. An advantage of the method is the rapidity with which experiments can be performed. Its correlation with various phases of pharmacological and physiological research offers great opportunity for advancement in our knowledge of vital processes.

Figure V illustrates the simple Warburg [9] type of constant volume manometer, which has a wide application in cancer research as well as in the study of many types of biological reactions involving the formation or disappearance of gas. It consists of a reaction vessel (capacity 16 to 20 cc.) to which is

[9] Warburg, O., "Ueber den Stoffwechsel der Tumoren." Berlin: Springer (1926). English trans. by F. Dickens, London: Constable (1930).

FIG. V.



The Warburg manometric apparatus with improved shaking device.

attached a small bulb permitting the introduction of reagents during the course of the experiment. The reaction vessel is connected, by means of a ground glass joint, to a short side-arm which in turn is joined to a U-tube of small bore (1 sq. mm. cross-section). The arms of the latter are about 30 cm. long, and graduated in millimeters. One end is open to the

atmosphere and the other carries a stopcock through which the reaction vessel can be connected with the atmosphere. The bottom of the U-tube is attached to a rubber reservoir filled with a suitable liquid, usually Brodie fluid,[9] which has a density such that 10,000 mm. is approximately equal to 760 mm. of mercury. By means of a screw-clamp arrangement, this liquid can be adjusted to any desired height in the arms of the U-tube. The apparatus is mounted on a wood support and attached to a shaking apparatus so that the reaction vessel is immersed in a constant temperature bath.

A simple and convenient shaking apparatus, in use in our laboratory, is illustrated in the photograph. The wood support is attached to the shaker by means of two deeply flanged nuts which fit into two notched brass cross-strips of the shaker. The lower of these strips is rigid, while the upper is free to move back and forth and is attached to a variable eccentric which in turn is connected to a variable-speed phonograph motor through a series of gears. The amplitude of the swing, as well as the rate of shaking, may thus be controlled at will. In general we have used an arc of 3 cm. and a rate of 120 complete oscillations per minute.

In carrying out an experiment, the gas concentration in the liquid phase is first brought into equilibrium with that of the free space in the reaction vessel. This is done by passing a stream of the appropriate gas (usually 5 per cent. CO_2 in nitrogen or 5 per cent. CO_2 in oxygen) through the apparatus for several minutes. The liquid in the U-tube is then brought up to some previously selected mark on the arm to which the reaction vessel is attached (say at 100 mm.) and the apparatus closed off. The level of the liquid will now be the same in the two arms of the U-tube. As gas is formed in the reaction, a pressure develops, which registers on the U-tube liquid. To make a reading the fluid is brought up to the previously selected mark, and the height of the liquid above this mark in the arm open to the air is read off. This value (h) represents the pressure developed by the gas formed, in terms of millimeters of U-tube fluid. By calculation, it may be converted into cmm. of gas formed (or disappearing) as follows.

It may easily be shown [9] that

$$x = h\left[\frac{V_g \cdot \frac{273}{T} + V_f\alpha}{P_0}\right],$$

where x represents cmm. of gas formed at N.T.P.; h, the pressure developed in mm. of U-tube fluid; V_g, the volume of free gas space in the reaction vessel; V_f, volume of the reaction liquid; T, absolute temperature of the thermostat; P_0, normal pressure (760 mm. Hg) in terms of mm. of U-tube fluid; and α, solubility of the gas in question in the reaction liquid (in cmm. of gas under standard conditions dissolved in 1 cmm. when in equilibrium with a partial pressure of the gas equal to P_0).

It will be seen that the expression in brackets will be a constant for any given gas with any given instrument. For calculating cmm. of gas formed from the manometer reading, we may put

$$x = hk,$$

where k is the so-called vessel constant. The latter depends upon the type of gas being absorbed or evolved, and must be determined for each manometer separately. The experimental work involved in this is the determination of the density of the U-tube fluid, and the volume of the free gas space above the liquid phase. The latter may be done by filling the space with mercury, weighing the mercury, and calculating the total volume from the known density. The total volume minus the liquid volume gives the volume of the gas phase.

The Warburg manometers are very sensitive to slight changes in temperature and barometric pressure. For this reason efficient thermostatic control of the waterbath is essential. Changes in barometric pressure are corrected for by means of an extra manometer containing a small amount of water. Any pressure changes occurring in this manometer are used to correct the h-values read on the reaction manometers.

The shape and size of the reaction vessels may be varied to suit the type of experiments being carried out. For example, when respiration or oxygen uptake is being measured, the

vessels must contain a small inset cup into which strong alkali is placed to absorb any free CO_2. The apparatus has been used extensively in our laboratory to measure the anaerobic glycolysis, or lactic acid formation, of cancer and other tissues. In this case the reaction medium must contain sodium bicarbonate, which neutralizes the lactic acid formed and results in the liberation of an equivalent amount of CO_2. The latter is then measured manometrically. We have also made an extended study of the enzyme glyoxalase,[10] which converts methylglyoxal, a carbohydrate intermediate, into lactic acid. As above, bicarbonate is used here also. Another application has been the measurement of blood arginase activity.[11] This enzyme decomposes arginine into urea and ornithine. The urea formed is decomposed by urease into CO_2 and NH_3, and the former is measured manometrically. Many other applications suggest themselves. An important advantage of the method, aside from the fact that very small amounts of material are required, is that the course of the reactions can be followed very easily at short time intervals.

VI. THE DIXON-KEILIN MANOMETRIC APPARATUS.

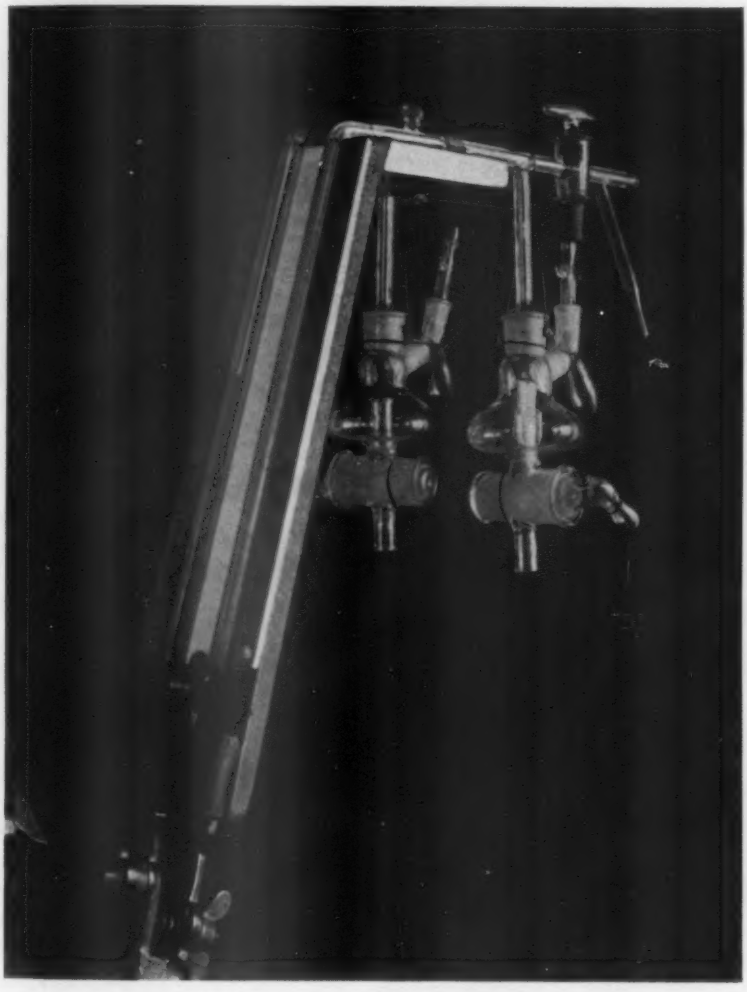
This is a development of the type of Barcroft differential manometer in use in Cambridge, England, for many years. It incorporates principles worked out by Warburg in Berlin and Dickens and Šimer in London, together with entirely new ideas of its authors. It solves the problem of how to measure simultaneously, and to differentiate, the oxygen uptake, respiratory CO_2 evolution, and CO_2 evolved or absorbed by acid formation or removal, on one sample of respiring material immersed in bicarbonate-containing medium and in an oxygen atmosphere containing CO_2 of the concentration (5 per cent.) necessary to maintain the physiological pH (7.4) of the bicarbonate buffered medium. The theory and practice of the method are described by its authors [12] and by Dixon,[13] and further practical details are given by Elliott and Schroeder.[14]

[10] Platt, M. E. and Schroeder, E. F., *J. Biol. Chem.*, **104**, 281 (1934).
[11] Weil, L. and Russell, M. A., *J. Biol. Chem.*, **106**, 505 (1934).
[12] Dixon, M. and Keilan, D., *Biochem. J.*, **27**, 86 (1933).
[13] Dixon, M., "Manometric Methods," Cambridge University Press, 1934.
[14] Elliott, K. A. C. and Schroeder, E. F., *Biochem. J.*, **28**, 1920 (1934).

In the following pages the apparatus and its use are briefly described.

The apparatus (Fig. VI) consists of two identical vessels connected by a differential manometer with Clerici solution

FIG. VI.



The Dixon-Keilin modification of the Barcroft differential manometer.

(density about 4) containing bile salt, as manometer fluid. The structure of the vessels is shown in Fig. VI *a*. To carry out an experiment, the half bored tap *T* is first filled with 40

FIG. VI *a*.

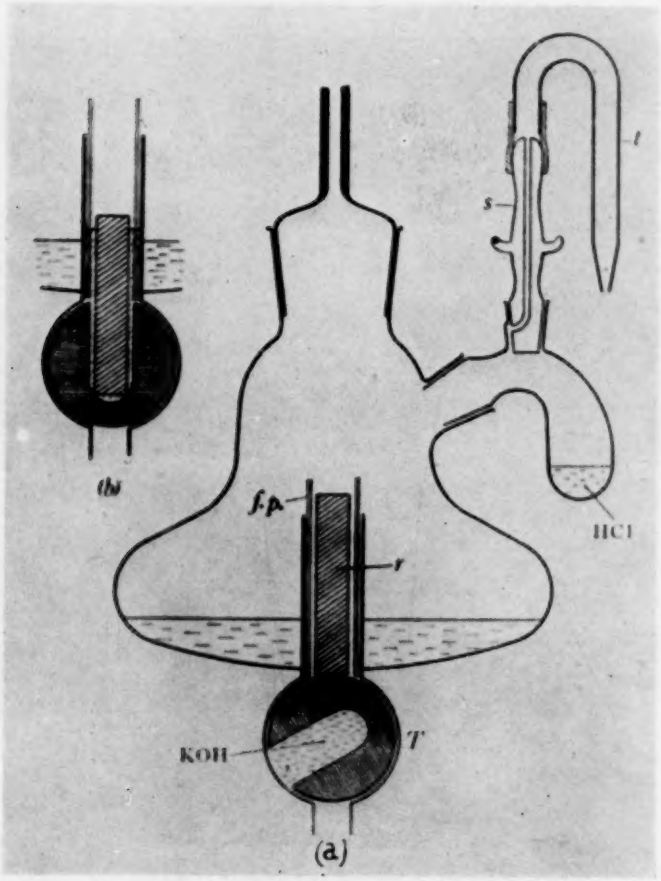
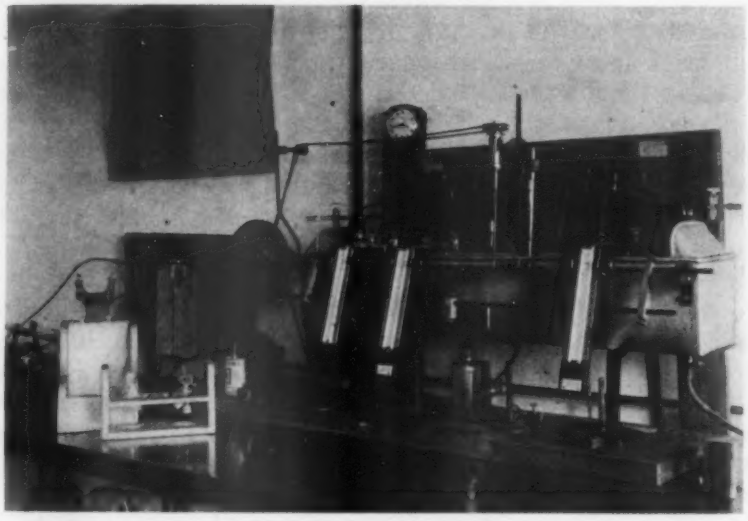


Diagram of the Dixon-Keilin manometer vessel.

per cent. KOH (with the manometer upside down) and the tap turned to the position shown at (*a*). A roll of filter paper (f.p.) is placed in the inner tube, and inside it a short glass rod (*r*), the joints are all carefully greased and secured with rubber

bands, and 0.3 cc. of 3 N HCl placed in the side bulb. The other vessel is prepared in the same way and into each is introduced exactly 3 cc. of Ringer solution containing 0.025 M sodium bicarbonate, and roughly the same weight of tissue is placed in each vessel. The vessels are then connected to the manometer which is fixed to the shaking apparatus with the vessels immersed in the thermostatically controlled water bath (Fig. VI *b*). By means of a gas-leading system the vessels are filled with a mixture of 5 per cent. CO_2 in oxygen, the gas being passed through the opening of the manometer

FIG. VI *b*.



Water-bath and shaking and gassing apparatus for use with Dixon-Keilin manometers.

and out through the side tube, *s*, (Fig. VI *a*) for 10 minutes at 200 cc. per minute per vessel. A bent tube (*t*) is attached to *s* so that the gas bubbles through the water in the bath, and the taps are adjusted to give the same rate of flow through each vessel. After gassing, the tube *s* of both vessels is turned so that the exit is closed and shaking is continued for 5 minutes to ensure equilibration of temperature in both vessels. Then the manometer taps are closed and at zero time the side bulb is turned so that acid flows into the left vessel and kills the tissue,

liberating at the same time all the CO_2 present as bicarbonate and any "bound CO_2" present in the tissue. The shaking is continued for the experimental period, 60 or 90 minutes. During this period the manometer, which is registering a positive pressure in the left vessel due to the CO_2 liberated, will move, the movement being a resultant of the effects on the pressure in the right vessel, of the O_2 uptake, respiratory CO_2 output and CO_2 liberated or absorbed by acid formation or disappearance. This total movement is termed h. At the end of the experimental period the acid is tipped into the right vessel killing the tissue and liberating all CO_2 from bicarbonate in the medium and tissue. The reading then obtained, h_1, represents the algebraic sum of O_2 uptake and respiratory CO_2 formed, since the pressure in the two vessels due to CO_2 liberated from the bicarbonate introduced originally will be equal. Finally the bottom stopper, T, of each vessel is turned up. The glass rod, r, drops into the hole in the stopper and displaces the KOH upwards so that it is absorbed on the large surface of the roll of filter paper and rapidly absorbs all CO_2 from the vessel. After allowing ample time for the absorption to take place completely, a reading, h_2, is taken which is determined solely by the oxygen uptake in the right vessel.

In order to work out the results it is necessary to calibrate the apparatus. This is done by measuring the volume by weighing the mercury required to fill it completely, and determining the cross-sectional area of the manometer tube and the angle at which the manometer stands. By means of an involved formula, constants are calculated, which, multiplied by the manometer reading, give the gas volume in $mm.^3$ at N.T.P. The constants for oxygen and CO_2 (k_{O_2} and k_{CO_2}) are different due to the difference in solubility in water of the two gases. It should be mentioned that it is essential that the total volumes of the two flasks should be almost exactly equal, otherwise h_1 readings will be misleading due to the different pressures developed in the two vessels on liberating the CO_2 from the bicarbonate.

By convention, gases evolved are regarded as positive quantities, gases absorbed as negative. The exchanges of gases are then given by the following algebraic equations:

$$O_2 \text{ (as mm.}^3\text{)} = h_2 \cdot k_{O_2},$$
$$CO_2 \text{ (as mm.}^3\text{)} = (h_1 - h_2) \cdot k_{CO_2},$$
$$\text{Acid (as mm.}^3\ CO_2 \text{ evolved)} = (h - h_1) \cdot k_{CO_2}.$$

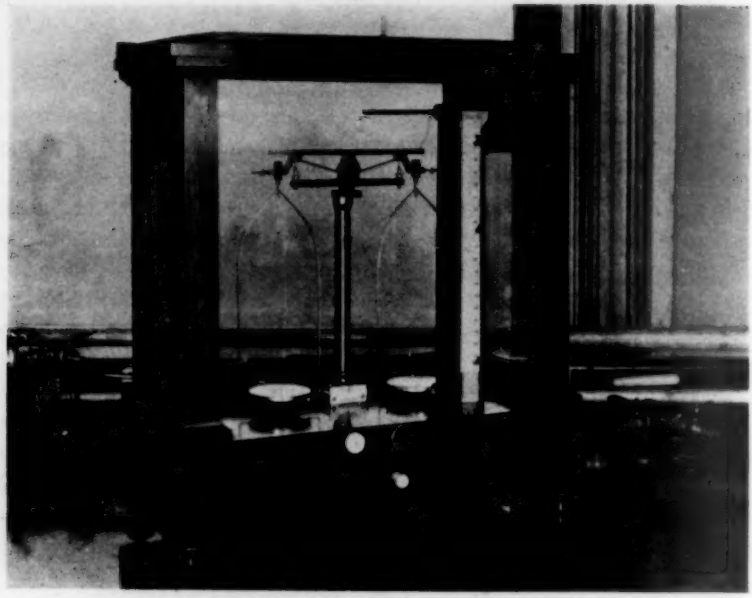
The method has so far been applied to measurements of the metabolism of thin slices of tissue, but there is no reason why this apparatus should not be used for the study of many reactions involving gas exchanges. A further device sometimes used consists in hanging a small cup by means of a short platinum wire hooked onto the central tube, as is shown in one of the vessels in Fig. VI. This tube can be shaken down so that its contents mix with the rest of the medium at any stage in the experiment desired. It is often desired to measure acid formation, etc., in the absence of O_2; for such anaerobic experiments the vessels are filled with N_2/CO_2 gas mixture. At the end of the experiment it is possible to wash out the vessels quantitatively and carry out chemical analyses on the solution. In this case the difference between figures obtained for the fluids from the left and the right vessels will represent changes taking place during the experimental period.

VII. A SIMPLE CHAINOMATIC BALANCE.

In studying the metabolism of living tissues by means of the manometric technique, it is necessary to obtain the wet weight of the tissue slices as rapidly as possible. A chainomatic balance seemed to offer the simplest and most inexpensive method of obtaining these weights. As the accuracy of the method only required weighing to approximately 1 mg., an accurate chainomatic balance was not required. The chainomatic principle was therefore adapted to an old analytical balance and this gave an accuracy of 0.5 mg. The chainomatic principle entails the use of a uniform gold chain, the effective weight or length of which may be varied. The sensitivity of the balance will depend upon the weight of the gold chain and the distance from the fulcrum of the balance at which the chain is attached. For any given weight of chain the closer it is attached to the fulcrum the greater will be the sensitivity.

The accompanying photograph (Fig. VII) clearly shows the method of construction. The rider arm was removed

FIG. VII.



A simple chainomatic balance for weighing small amounts of tissues.

from its position directly above the beam of the balance and offset slightly. A tight-fitting spool was attached to it and a belt of silk ribbon was stretched over this pulley and a freely moving pulley attached to the floor of the balance directly below it. A pin through the ribbon served as a pointer to an attached scale and as a means of anchoring the loose or movable end of the gold chain. The fixed end of the chain was attached to a piece of copper wire soldered to the right hand end of the balance beam. The length of the chain and hence the effective weight on the right hand side of the balance may be increased by turning the rider arm, thus lowering the pointer to which the movable end of the chain is attached. In order not to place the tissues directly on the left pan of the balance a small hook was made of gold wire and suspended from the left hand stirrup to hold the tissues during weighing. This also helped to balance the total weight of the gold chain on the other side.

The balance is very easily calibrated if the chain is uniform, for then the relation of the movement of the pointer to the weight added will be linear and equal to one-half the unit weight of the chain. The gold chain in this instance weighed approximately 44 mg. per inch. As the scale used was graph paper ruled in 20 divisions to the inch, in order to have each division equal to one milligram, the fixed end of the gold chain was attached to the beam about 10 per cent. beyond the right stirrup knife edges. The copper wire could then be bent slightly by trial and error so as to make the weights correspond with the scale.

VIII. THE LINDERSTRØM-LANG AND HOLTER MICRO-METHOD FOR ENZYME STUDY.

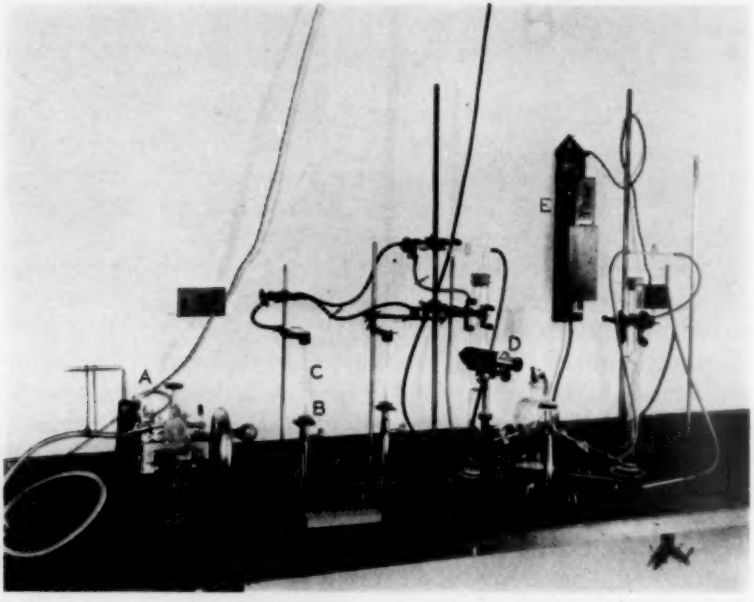
This method depends upon application of the technique of micro-chemistry to the study of enzymes in tissues. It is probable that the distribution of any particular enzyme is not uniform throughout the tissue, but varies with the morphological structure, and state of the cells. The particular advantage of the new method is that it permits the determination of enzyme activity in very small amounts of tissue, the nature of which can be accurately described by histological examination under the microscope. In this way, correlations can be made between the type of cell and its enzymatic activity. Such correlations should be of great value in elucidating the function of the various enzymes in the cell. For example, of particular importance in cancer research is the question of the enzymatic changes occurring during the process of cell division, as well as the enzyme content of the various histologically differentiated parts of cancer tissue.

The originators of the method state that, under ideal conditions, it should be possible to demonstrate, and measure accurately, the enzymatic activity of as few as 10 cells. The method is thus about 7000 times more micro than the ordinary macro methods, but requires corresponding care and accuracy. Still the method is easily within the limits of average experimental skill, and has great possibilities of development in many phases of biochemical study.

In carrying out the method, a cylinder of the tissue under examination (1 to 2 mm. in diameter) is cut into sections of

the desired thickness by means of a freezing microtome. Depending on the enzyme content of the tissue, these sections are from 15 to 25 μ thick. Under ideal conditions, alternate sections are taken for the enzymatic determination and for the histological examination, making the reasonable assumption that adjacent sections are practically identical with respect to type of cells. In some cases, it is found necessary to examine histologically the tissue surrounding the region from which the cylinder has been taken.

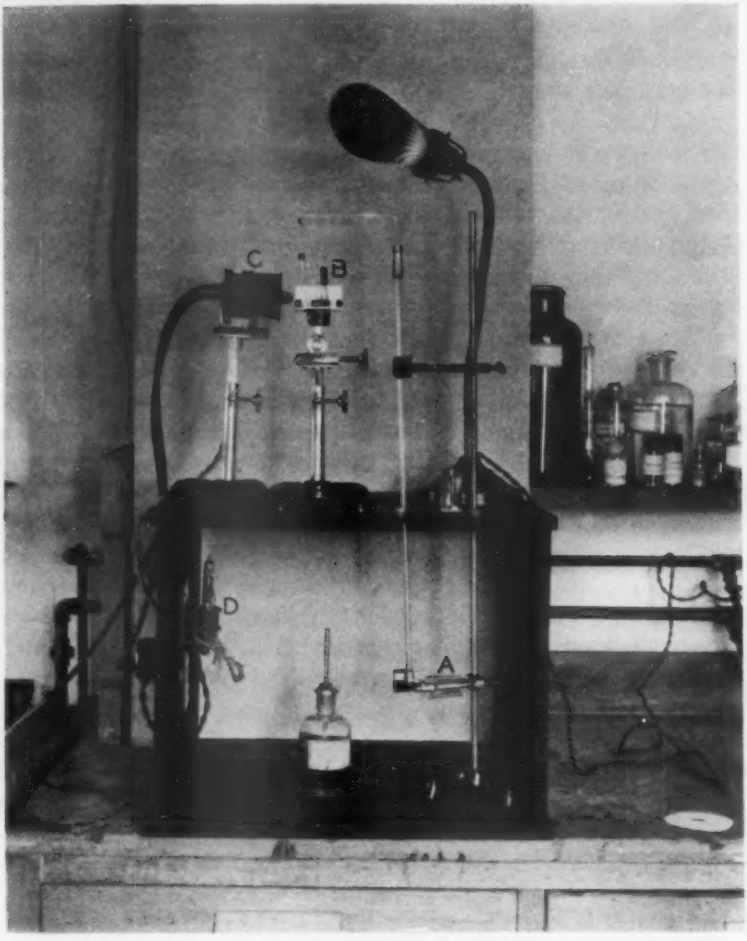
FIG. VIII.



Freezing microtome and pipetting arrangement for Linderstrøm-Lang and Holter micro-enzyme apparatus. *A*, freezing microtome; *B*, reaction vessel; *C*, pipette; *D*, telescope; *E*, electrically controlled constant pressure air pump.

In principle, the method for determining enzyme activity is a refined micro titration. Figures VIII and VIII *a* illustrate the apparatus used, which may be purchased from F. C. Jacob Glastekniske Vaerksteder, Copenhagen, Denmark. In Fig. VIII, *A* is the rotary freezing microtome. The slice of tissue under examination is placed in a small reaction vessel (*B*) whose capacity is about 250 cmm. Appropriate volumes of

FIG. VIII *a*.



Micro burette for Linderstrøm-Lang and Holter micro-enzyme apparatus. *A*, micro-screw; *B*, color standard; *C*, electromagnet; *D*, interrupter for electromagnet.

the required substrate and buffer solutions are introduced into the vessel by means of micro-pipettes (*C*) graduated to deliver 7, 10, etc., cmm. of fluid. The level of liquid in the pipettes is observed through the telescope, *D*. *E* is an electrically controlled constant pressure air pump which expels the fluid from the pipettes at a uniform rate.

After incubation of the reaction vessel for the desired length of time at constant temperature, the enzyme action is stopped, for example by addition of acetone, alcohol, or formaldehyde, containing an appropriate acid-base indicator. Any changes which have occurred in the substrate due to enzymatic action are then determined by titration. Figure VIII *a* illustrates the micro-burette used for this. It consists essentially of a capillary tube accurately graduated, ending in a very fine tip. The lower part of the burette contains mercury in contact with the standard solution above it. The level of the mercury may be accurately controlled by means of the micro-screw, *A*. As the level is raised, the standard solution is forced out through the tip into the reaction vessel. The end point of the titration is determined by comparison to a color standard, *B*. For stirring the mixture, a small glass bead containing iron powder is introduced into the reaction vessel. This bead is agitated by the electromagnet, *C*, which is connected in series with an interrupter, *D*. From the amount of standard solution required to reach the end point, the enzymatic change may be calculated. The burette is calibrated in steps of 0.2 cmm., and may be read (by estimation) to 0.02 cmm. Under favorable conditions, check determinations agree within 1 per cent.

Thus far the method has been applied to the study of about 10 different enzymes, among them arginase, peptidase, pepsin, trypsin, desamidase, lipase, and the carbohydrases. The exact details of the method will of course vary for each enzyme. The reader is referred, for these details, to the original papers of Linderstrøm-Lang and Holter.[15]

IX. A HIGH VACUUM DISTILLATION APPARATUS.

The problem of distillation (or sublimation) is primarily one of removing molecules from the liquid (or solid) phase to the gas phase, and to do this one must supply the energy difference between molecules in two phases plus more or less kinetic energy to send the liberated molecules on their way. The magnitude of this energy difference (heat of vaporization or sublimation) is determined by the cohesive forces of the

[15] Linderstrøm-Lang, K. and Holter, H., *Ergebnisse d. Enzymforschung*, III, 309 (1934).

molecules. These forces are determined in turn by the chemical nature of the substance. For organic compounds one can assign to each type of group, e.g., $-CH_2-$, $-COOH$, $-NH_2$, $-OH$, etc., a numerical value for the contribution to the intermolecular cohesive forces arising from that group, and these values are, to a rough approximation, additive. So one can get some idea of the firmness with which the molecules of a compound of known structure are bound to one another by adding the cohesive forces of all its constituent groups. As would be expected, the more polar groups exert a stronger attractive force on the molecules, while the non-polar groups exert little (relative) restraint on other molecules. Thus Meyer and Mark [16] give values for many of the common organic groups from which the following are drawn for purposes of illustration: $-CH_3$ and $=CH_2$, 1780 cals.; $-CH_2-$, 990; $-COOH$, 8970; and $-OH$, 7250.

In distillation or sublimation, the energy required to overcome these cohesive forces is supplied by raising the temperature. This thermal energy, however, can be absorbed by the molecules and used to increase their internal vibrational energy. If the vibrational energy in any bond becomes greater than the binding energy between the two atoms involved, the bond breaks and the molecule decomposes. Now one can obtain from heats of combustion and dissociation the binding energies associated with different types of bonds. Thus the binding energy in calories per formula weight for the C – H bond is 92,000; for the C – C bond (aliphatic), 71,000; for the C – C bond (aromatic), 96,000, etc.

From the values for cohesive forces and binding energies, one can estimate roughly whether distillation is permitted. If by raising the temperature, the intermolecular cohesive forces are overcome before the energy absorbed exceeds the binding energy of the weakest bond, distillation results. Thus Hill [17] found that he could distil the straight chain hydrocarbon C_7H_{142}; from the figures given above, one sees that the molecular cohesion is $2 \times 1780 + 68 \times 990 = 71{,}000$

[16] Meyer, K. H. and Mark, H., "Der Aufbau der Hochmolecularen Organischen Naturstoffe," Academische Verlagsgesellschaft, 1930, p. 32. See also Dunkel, M., *Zeit. physik. Chem.*, **42**, 138 (1928).

[17] Hill, J. W., *Science*, **76**, 218 (1932).

cals., while the strength of the weakest bond (C — C) is also 71,000 cals. Of course, all the internal vibrational energy is not concentrated in any one bond, especially in so large a molecule, so that decomposition does not necessarily occur, but one would not expect to get distillation of much higher members of the series. On the other hand, Hill found that $C_{80}H_{162}$ decomposed before distilling (molecular cohesion, 81,000 cals.; binding energy of weakest bond, 71,000 cals., as before).

This dependence of distillation upon a balance between molecular cohesion and binding energy is not changed when one works at low pressures.* The same amount of energy must be supplied. But even at low temperatures, there is a certain fraction of the molecules in a liquid having energies considerably in excess of the mean energy corresponding to prevailing temperature. Those molecules which reach the surface with sufficient excess energy to overcome the cohesive forces can escape into the gas phase. If the mean kinetic energy (indicated by the temperature) is well below the energy required for vaporization, the number of such escaping molecules will be small. At ordinary pressures, therefore, they will all be beaten back into the liquid by impacts from molecules in the gas phase. As one removes these opposing molecules, i.e., lowers the pressure, one increases the probability that a molecule escaping from the liquid will reach the condensing surface. Finally, when the pressure is so low that the mean free path of gas molecules (i.e., the distance they travel without collision) is greater than the distance from the distilland to the condenser, all the molecules of the liquid acquiring sufficient energy to escape by reason of a series of favorable collisions and leaving the surface in an approximately normal direction will strike the condenser.

The difference between the mean kinetic energy of the molecules at a given temperature and the intermolecular cohesion determine the vapor pressure of the substance at that temperature. When all "foreign" gases are removed, the

* Much of the theoretical groundwork in high vacuum distillation has been laid by Langmuir and by Washburn. Various types of apparatus suitable for different purposes have been designated by Hevesy, Langmuir, Washburn, Hickman, Carothers, Hill, and others.

rate of distillation depends upon the vapor pressure, the extent of the exposed surface of material, and the usual factors determining the velocity of gas molecules at the given temperature. Langmuir derived the following expression for n, the number of moles of substance of molecular weight M distilling per second:

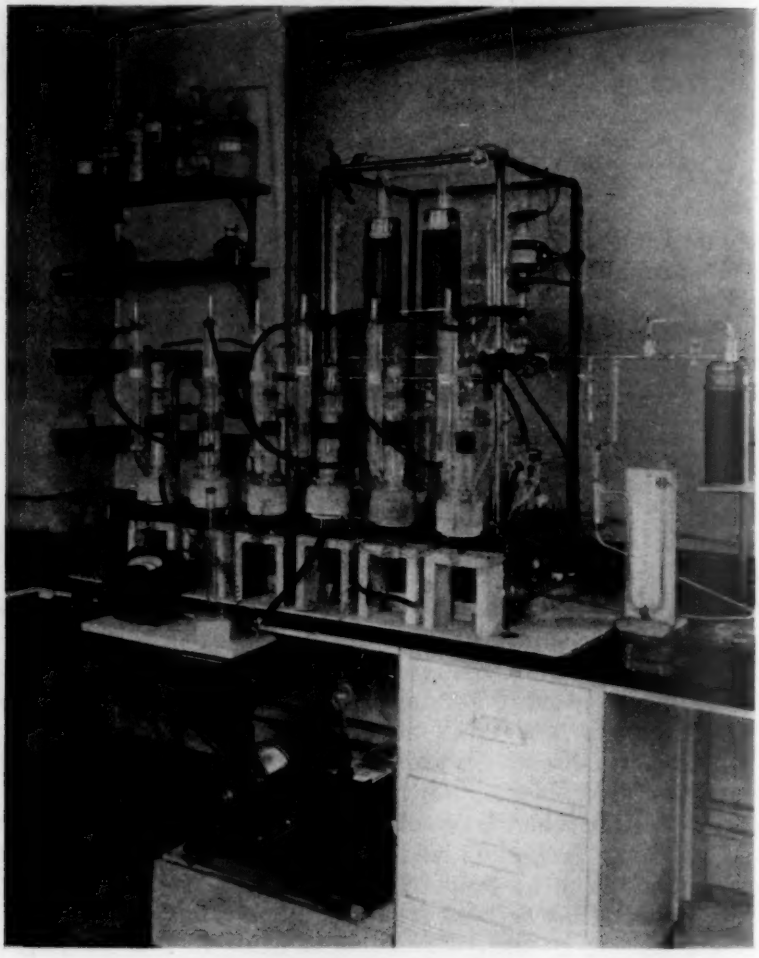
$$n = \frac{pS}{(2\pi MRT)^{1/2}},$$

where p is the vapor pressure at the evaporating surface at temperature T and S is the effective area of the evaporating surface. R is the gas constant.

Besides increasing the rate of distillation at a given temperature by increasing the mean free path of the gas molecules, the high vacuum technique influences the distillation in other ways. At the low pressures used in this laboratory (of the order of 10^{-6} mm. Hg.) oxygen is, for all practical purposes, completely absent; this fact often enables one to raise the distilland to considerably higher temperatures than would otherwise be possible. Washburn and his co-workers found this to be true in the vacuum distillation of petroleum, while in this laboratory we have been able to heat enzymes to much higher temperatures than are usually possible (see below). Furthermore, all water is removed, and this fact may account for the observed greater stability of certain organic compounds toward heat in vacuo. Of course, this condition may operate in the reverse direction and promote reactions that would not otherwise take place. Thus Carothers and Hill took advantage of the removal of volatile condensation products such as water in preparing some very high molecular weight compounds such as polyesters and polyamides. The same phenomenon may account for the failure we have experienced in attempting to distil some amino acids of low molecular weight. Two or more molecules may condense to form polypeptides with, of course, lower vapor pressures.

The apparatus developed and used in this laboratory for the high vacuum distillation of biological products is shown in the accompanying photograph (Fig. IX). A diagrammatic sketch showing construction is also given (Fig. IX *a*). We have used only solids in this work. The material under study

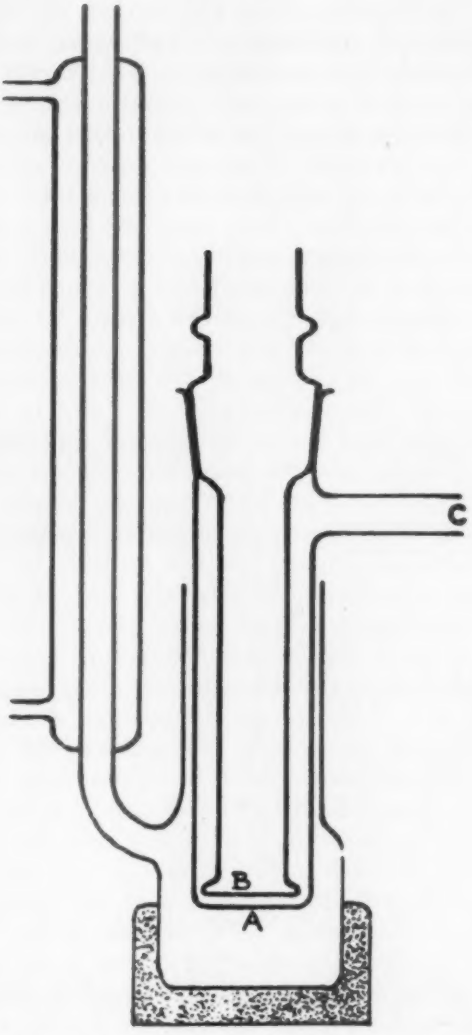
FIG. IX.



The high-vacuum distillation apparatus.

is placed as a thin layer on the bottom of tube *A* (Fig. IX *a*). The condensing surface, *B*, only 2 or 3 mm. from the solid, is cooled by a solid CO_2—acetone mixture or in some cases by circulating cold water. The system is evacuated through *C* by a two-stage mercury diffusion pump backed by a Hyvac oil

FIG. IX½a.



Sketch of still for high-vacuum distillation apparatus.

pump. Two traps cooled in solid CO_2 and acetone are placed between the stills and the pump to prevent the mercury from the latter depositing on the condensers and also to protect the

oil pump. If the ground joints between tube *A* and condenser *B* and between the still and the vacuum line are carefully made and properly lubricated, vacua of less than 10^{-6} mm. Hg are readily attained and maintained. Of course, if volatile products are given off when the material is heated, the pressure rises, but under the most adverse conditions we have yet met, the pumps have been able to keep the pressure below 0.001 mm.

The materal in the stills is heated in constant temperature baths of boiling liquids. This has been found to be a most satisfactory arrangement, requiring practically no attention. The upper portion of the baths (see Fig. IX *a*) is only slightly larger in diameter than the stills; a piece of Gooch rubber tubing around the still and the top of the bath closes the latter. The reservoir, of Pyrex glass, is covered with a thin layer of asbestos cement, then a coil of resistance wire is wound on the bottom and part way up the sides, and this heating unit is covered with about half an inch of asbestos cement. After thorough drying the asbestos is painted with a water-glass solution. The heaters may be run directly from the 110 volt line; for most temperatures, two heaters may be run in series.

We have been able to distil the following substances: glucose and sucrose (previously done by other investigators); simple amino acids such as glycine, glycine anhydride, lysine dihydrochloride, and the dipeptide leucyl-glycine. Ascorbic acid (vitamin C) distils unchanged at about 175°. Of particular interest to us were the carcinogenic compounds; 1 : 2 : 5 : 6-dibenzanthracene is readily purified by sublimation at 140°; slower sublimation occurs even at 100° (m.p. about 260). Chrysene also sublimes readily. Cholesterol distils very rapidly at 100°. Although the distillation was unsuccessful, the results obtained with the enzyme steapsin are of considerable interest. The activity of the enzyme was completely destroyed after heating for two hours in an oven at 135°. But there was only a slight loss after heating for ten hours at 160° in vacuo, and the enzyme was still active after it had been heated for 13 hours at 140–160° followed by 10 hours at 180°.

NOTES FROM THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

RADIOACTIVITY INDUCED BY NEUTRON BOMBARDMENT.*

BY

ARTHUR BRAMLEY.

The experiments of Fermi[1] and Dunning (unpublished results on the induced β-particle emission from elements bombarded by neutrons) give added information concerning the nature of the nucleus. It leads to the idea that the ensemble of protons and neutrons forming the nucleus exert an appreciable force on the negative energy electrons within the nucleus and are thus capable of producing pairs—positron and electron. Whether this process occurs will depend on the value of the transition probability from the state in which the ψ-function represents the initial ensemble of protons and neutrons to that state in which the ψ-function represents the final ensemble of protons and neutrons together with a pair, positron and electron.

Thus if we have a reaction in which the neutron is captured by the element ${X_\rho}^m$ and remains in that nucleus in an excited state, then through the possibility of the formation of a pair the following reaction can take place: the combination of the neutron with the positron to form a nuclear proton with the subsequent emission of the electron provided a transition is possible from the element ${(X + n)_\rho}^{m+1}$ to the element ${(X + n)_{\rho+1}}^{m+1}$. The possibility of this latter transition will depend on the value of the transition probability from the ψ-function representing the state ${(X + n)_\rho}^{m+1}$ to the ψ-function representing the final state ${(X + n)_{\rho+1}}^{m+1}$ together with a free electron. The idea that the selection rules governing the transition probability are a determining feature in nuclear reactions has been developed previously by Fermi,[2] and Bramley.[3]

* *The Physical Review*, June 15, 1934.

[1] Fermi, *Nature*, **133**, 757 (1934).

[2] Fermi, *Zeits. f. Physik*, **88**, 161 (1934).

[3] Bramley, *Science*, **79**, 160 (1934).

Only further experiments can decide whether the nuclear pairs are produced by the nuclear protons or whether the neutrons have the power themselves to produce pairs.

These selection rules must be such that there cannot be more protons in the nucleus than neutrons, e.g., the series, $H^1D^2T^3He^4$. These rules indicate that T^3 should have a very small chance of forming a pair with the subsequent formation of He^3 and the emission of a free electron whereas T^3 should react readily with neutrons to form He^4 with the emission of a free electron. Whether the excess energy will appear as energy of the free electron or as hard γ-rays it is impossible to state.

We shall take as our final example, the case of the neutron bombardment of carbon. The reaction $C_6^{13} + n_0^1 \rightarrow C_6^{14} \rightarrow N_7^{14} + \epsilon^-$ is possible on this model but a radioactive reaction following the formation of $C_6^{13}C_6^{12} + n_0^1 \rightarrow C_6^{13}$ is improbable as C_6^{13} cannot make a transition to another existing element with the emission of an electron.

The process by which the nuclear electron, formed as one entity of the pair, escapes from the nucleus, is difficult to imagine. It may be that the nuclear barrier for electrons is much lower than we have supposed: the calculations of Kemble and Present[4] on the fine structure of Hα indicate an effective nuclear radius of 5×10^{-12} cm.; the calculations of the writer[5] on the formation of x-rays by high energy electrons lead to a similar conclusion; the reaction $D^2 + D^2 \rightarrow T^3 + H^1$ requires an even larger effective collision radius to explain the rate of reaction.

MEASUREMENT OF ABSOLUTE X-RAY INTENSITIES AND ABSOLUTE SENSITIVITY OF X-RAY FILM WITH A GEIGER-MÜLLER COUNTER.*

BY

G. L. LOCHER and D. P. LEGALLEY.

The work reported here concerns the use of a counter for measurements of feeble x-ray intensities, by means of the

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[4] Kemble and Present, *Phys. Rev.*, **44**, 1031 (1933).

[5] Bramley, *Nature*, **133**, 259 (1934).

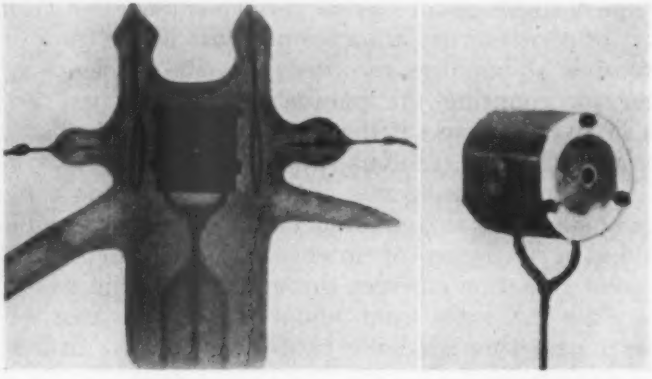
* *The Physical Review*, Dec. 15, 1934.

photoelectric action of the x-rays on the gas of the counter. By this method it is possible to make absolute measurements of the flux of x-radiation with as good accuracy as that with which the energy-distribution of the incident radiation and its absorption coefficients in the *gas* are known.

Almost monochromatic fluorescent x-rays are used. Absolute intensities are determined by measuring the counting rates, using the efficiency of the counter as computed from the energy-distribution of the incident rays, the absorption coefficients of the gas, and the thickness and pressure of the gas. The counter thus forms a small ionization chamber in which the number of individual photoelectrons is counted, instead of measuring the amount of ionization in the customary manner.

Figure 1, (*a*) and (*b*), are respectively, an x-ray photograph of the counter and a photograph of its cylinder-electrode

FIG. 1.



a. *b.*

X-ray photographs of apparatus.

(cathode). The x-rays enter and leave the counter through "bubble" windows of very thin glass, concave inwards. A narrow pencil of rays passes through the counter along a transverse diameter of the cylinder, in such a way as to miss the wire electrode, which is slightly off center. The cathode is a heavy gold-plated brass cylinder, 1.0 cm. in diameter and 1.8 cm. long, slightly flared at the edges. Two small lead

blocks inserted in its walls collimate a beam of rays 0.0062 cm.^{2} in cross section by means of holes, respectively, 0.089 cm. and 0.225 cm. in diameter, for the entrance and exit of the rays. The inner surfaces of the windows are covered with cellophane disks, 0.0025 cm. thick; these are sufficient to exclude the entrance of electrons liberated elsewhere than inside the cylinder, but their total absorption is so small that the scattering and photoelectron emission from the cellophane itself may be neglected. The ends of the cylinder are covered with disks of thick mica, to prevent stray ions from diffusing into the sensitive region. The wire electrode is of bare tungsten, 0.0076 cm. in diameter. The gas consists of approximately 98.5 per cent. krypton and 1.5 per cent. xenon at 6.31 cm. of mercury, at 27.35° C.

Apart from the loss of impulses due to plurality of discharges falling within intervals less than the resolving-time of the apparatus, for which correction is applied, and the spurious discharges due to radiations of various kinds, there is assumed to be a one-to-one correspondence between the number of photoelectric absorption events in the counter and the number of impulses recorded; i.e., the efficiency of the counter for counting the photoelectrons liberated in it is taken as $1 - \epsilon$, where ϵ is the loss due to multiple discharges occurring within the resolving-time of the apparatus.

A special x-ray tube was constructed. It has a molybdenum anode and a zirconium metal fluorescer arranged inside the tube in a region of intense radiation density. The fluorescent radiation emerges through a very thin window of Pyrex glass. X-rays from about 1.06 cm.^{2} area of the fluorescer pass through holes in a series of lead baffles into the counting tube.

The incident radiation is assumed to be purely fluorescent Zr *K*-radiation, with wave-lengths and energy distribution as given in Table I.

The fraction of the x-rays absorbed in the gas is calculated on the basis of the wave-lengths and energy-distribution given above, the pressure and constitution of the gas, and the length of path in the counter. In krypton and xenon, the scattering may be neglected, as compared with the fluorescent absorption. The atomic fluorescent absorption coefficients,

TABLE I.

Energy-distribution of Zr K-radiation.

Wave-lengths.

$K\alpha_1 = 0.7843$A $\qquad K\beta = 0.7005$A

$K\alpha_2 = 0.7885$A $\qquad K\gamma = 0.6883$A

Weighted mean $K\alpha = (2K\alpha_1 + K\alpha_2)/3 = 0.7857$A

Energy-distribution.

$K\alpha/K\beta = 5.38$; $\qquad K\beta/K\gamma = 9.0$;

or $\qquad K\alpha : K\beta : K\gamma = 48.42 : 9 : 1$

Relative numbers of quanta.

$N_{K\alpha} : N_{K\beta} : N_{K\gamma} = 0.845 : 0.140 : 0.015$

τ_a, of the gas are calculated from the formula of Richtmyer and Warburton, in Table II.

TABLE II.

Atomic fluorescent absorption coefficients $\times 10^{20}$.

	Krypton.	Xenon.	98.5% Kr + 1.5% Xe.
$K\alpha_{1,2}$	1.857	1.362	1.818
$K\beta$	1.294	0.965	1.289
$K\gamma$	1.225	0.913	1.220

The number of atoms per cc. in the gas (98.5 per cent. Kr + 1.5 per cent. Xe at 6.312 cm. mercury, at 27.35° C.) is 2.043×10^{18}. The absorbing path in the counter is 1.079 cm.

From the data given above, we get the fractions $f_{K\alpha}$, $f_{K\beta}$, and $f_{K\gamma}$, of the $K\alpha$, $K\beta$, and $K\gamma$ radiation absorbed in the counter, namely,

$$f_{K\alpha} = 1 - e \exp\left[-\tau_{K\alpha}x\right] = 0.0393,$$
$$f_{K\beta} = 1 - e \exp\left[-\tau_{K\beta}x\right] = 0.0280,$$
$$f_{K\gamma} = 1 - e \exp\left[-\tau_{K\gamma}x\right] = 0.0265.$$

For the mixture of radiation in the beam, we have the total fraction, f, absorbed: $f = 0.0375$ or 3.75 per cent. If every photoelectron discharges the counter, the total efficiency is, accordingly, 3.75 per cent.

A "standard" x-ray beam has been calibrated for use in measurements of the sensitivity and blackening of films. Table III gives the data on this beam and illustrates the method by which the counter was used to calibrate it.

TABLE III.

"Standard" beam of fluorescent Zr x-rays.

Voltage applied to counter: 680 ± 0.1%
Area of beam traversing counter: 0.0062 cm.²
Distance between fluorescer and counter: 58.8 cm.
Potential applied to x-ray tube: 29,400 volts, peak, ± about 5%; constant to about 1%
Current through x-ray tube: 0.003 ampere ± about 1%
R_D = "accidental" counting rate: front aperture of counter covered, x-ray tube running, = 61.8 min.$^{-1}$ ± 1.26% (6300 impulses)
R_L = correction for light from tube filament = 6.5 min.$^{-1}$ ± 7.1% (196 impulses)
R_T = total rate of counter, with apertures open, = 281 min.$^{-1}$ ± 0.58% (29,600 impulses)
R_X = rate due to x-rays, only, = 213.6 min.$^{-1}$ ± about 1%
N_C = No. quanta passing through counter per minute = 26.67 × 213.6 = 569.67
N_0 = No. quanta cm.$^{-2}$ min.$^{-1}$ = 5696/0.0062 = 9.03×10^5, approx.
N_0' = No. quanta cm.$^{-2}$ sec.$^{-1}$ = 1.50×10^4, approx.

MEASUREMENTS ON X-RAY FILM.

Eastman Ultra-Speed Duplitized X-Ray Film was used in the experiments described below. In all exposures, the x-rays were incident on the side of the film which has the heavy emulsion.

The energy flux at the film (57.3 cm. from the fluorescer) was approximately 9.57×10^5 quanta cm.$^{-2}$ min.$^{-1}$, or 1.60×10^4 cm.$^{-2}$ sec.$^{-1}$. The samples of film were held between sheets of opaque paper in a heavy brass cassette which was perforated on both sides for the entrance and exit of the x-rays.

Minimum Number of Quanta for Detectable Blackening.

Films were exposed to the standard beam for a series of short intervals and developed under identical conditions. An exposure of about 45 seconds gave visible blackening; this corresponds to 7.2×10^5 quanta per cm.² The sensitivity of this film seems surprisingly high.

Absorption Coefficients of Film, Emulsion and Celluloid.

These were determined by measuring the counting rates with the standard beam, filtered, respectively, through 10 thicknesses of film (0.250 cm.) and 10 thicknesses of celluloid from which the emulsions had been dissolved away (0.204

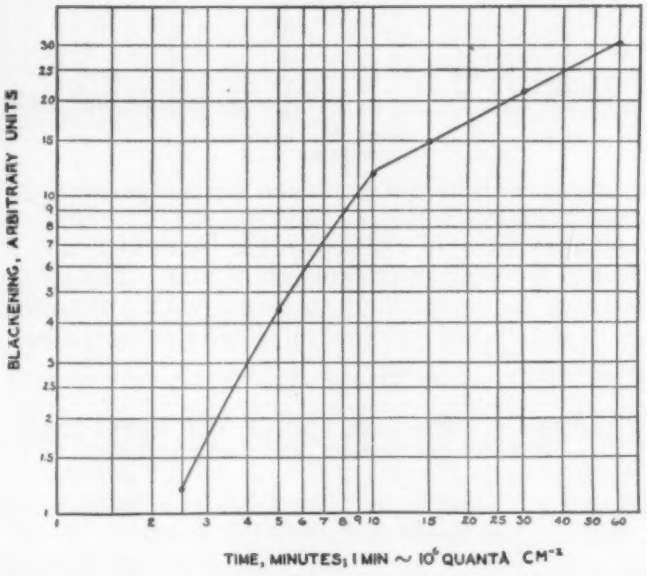
cm.). The total absorption coefficients found in this manner are: $\mu_{film} = 8.63$ cm.$^{-1}$; $\mu_{celluloid} = 1.66$ cm.$^{-1}$; $\mu_{emulsion} = 13.0$ cm.$^{-1}$. These values are subject to any error arising from modification of the wave-lengths and energy-distribution while passing through the absorbing material. The results are believed to be reliable to within 10 per cent.

Using the coefficients given above, we may calculate the number of quanta absorbed in the emulsion, for detectable blackening. This is approximately 4.1×10^4 cm.$^{-2}$.

Time-blackening Experiments.

Figure 2 shows the time-blackening curve for the film, which was exposed to the standard beam for intervals of 2.5 to 60

FIG. 2.

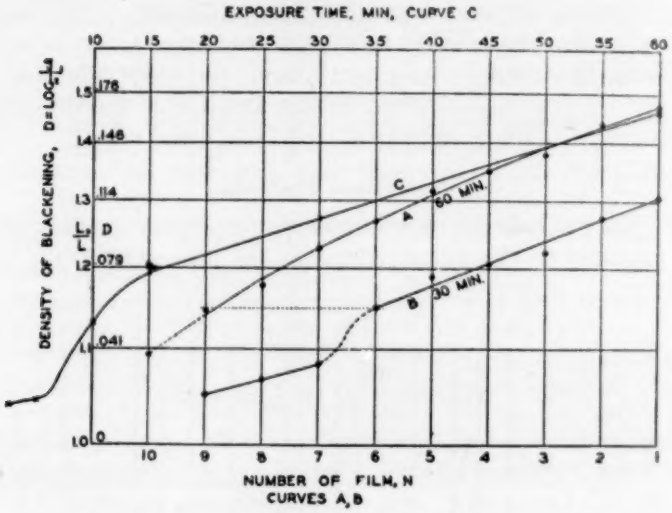


Blackening of film exposed to x-rays.

minutes. The "blackening," as measured with a densitometer, is defined as the difference between the amounts of light transmitted through the background of the film and the exposed spot, respectively, called L_0 and L. These data are

also shown in curve *C*, Fig. 3, in which the "density of blackening," *D*, is plotted against time. *D* is defined thus: $D = \log_{10} L_0/L$.

FIG. 3.



Blackening of films through which the x-ray beam passed successively.

In another series of exposures, the beam of x-rays passed successively through 10 thicknesses of film. The blackening of successive films was then measured with a densitometer. Curves *A* and *B*, Fig. 3, show the results for exposures of 60 and 30 minutes.

THE VARIATION WITH ALTITUDE OF THE PRODUCTION OF BURSTS OF COSMIC-RAY IONIZATION.*

BY

C. G. and D. D. MONTGOMERY.

The rate of occurrence of bursts of ionization from 140 pounds of lead shot was measured in a 50 liter magnesium ionization chamber filled with nitrogen at 14.5 atmospheres pressure at four elevations between sea level and the summit of Pike's Peak (4,300 meters). The ionization chamber was

* *The Physical Review*, March 15, 1935.

so designed as to minimize the random fluctuations of the cosmic-ray ionization allowing bursts of relatively small sizes to be measured.

The variation with elevation of the rate of occurrence of bursts of all sizes greater than 1.5×10^6 ions was found to be the same. The increase in the rate of occurrence with elevation was found to be very large, and increasingly greater at higher elevations. It was found that the relative frequency of bursts at any elevation was approximately proportional to the square of the total cosmic-ray ionization. The following table indicates the results.

Elevation (meters)	61	1860	3500	4300
Depth below top of atmos. (m. of water)	10.27	8.25	6.73	6.04
Relative number of bursts	1	3.04	13.8	26.6
Relative ionization squared	1	3.24	12.3	22.8

The variation with elevation shown above has a simple interpretation in the light of a recent theory of W. F. G. Swann.[1]

THE SIGNIFICANCE OF J. CLAY'S IONIZATION DEPTH DATA IN RELATION TO THE NATURE OF THE PRIMARY COSMIC RADIATION.*

BY

W. F. G. SWANN, Director

The latitude and directional effects in cosmic radiation necessitate the existence of charged particles entering our atmosphere with energies greater than 10^{10} electron-volts. These particles, if of electron type, would, in passage through the atmosphere, lose but a fraction of their energy, so that they would arrive at the earth's surface with energies comparable with 10^{10} volts.

The latitude and directional effects necessitate the assumption that about 14 per cent. of the rays observed at sea-level are of energy greater than 10^{10} volts. On the other hand, it has been frequently asserted that cloud-chamber experiments

[1] W. F. G. Swann, *Phys. Rev.* **47**, 575 (1935).

* *The Physical Review*, Sept. 1, 1934.

show far fewer rays than this number with energies comparable with the amount in question.

In a former communication [1] the writer has pointed out that harmonization of the cloud-chamber experiments and the latitude and directional effects in these matters necessitates the assumption that corpuscular rays of sufficiently high energy (energy comparable to 10^{10} volts) do not ionize in the sense of producing ions at the rate of about 50 in each centimeter of their path at atmospheric pressure. It is inferred, however, that they do produce from time to time showers of secondary rays of lower energy. These showers perpetuate the directions of the non-ionizing primaries, and hand on these directional characteristics in Geiger counter experiments. They would hand them on even in cloud-chamber experiments, where, however, the secondary rays would reveal themselves only with the actual energies they possessed, i.e., with energies smaller than those of the primaries. The writer has further given theoretical reasons to substantiate the reasonableness of an absence of ordinary ionization in the case of very high energy primaries.[2] He has also pointed out [3] that the existence of such a state of affairs would result in a diminution of ionization in a vessel with increase of depth of the vessel below the surface of the medium (say water) until a depth was reached at which the primary rays had lost enough energy to bring them into the region of energy in which they could ionize. Below this depth, the observed ionization in the vessel should show an increase followed by a decrease to zero in a range comparable with that representative of the total range of ionization of the primary particles in the medium.

In a recent communication,[4] J. Clay has found, at great depths, an increase of ionization followed by a sharp decrease to zero, the whole phenomenon being in harmony with the predictions cited above. The object of the present note is to call attention to this fact and to trace its significance in some-

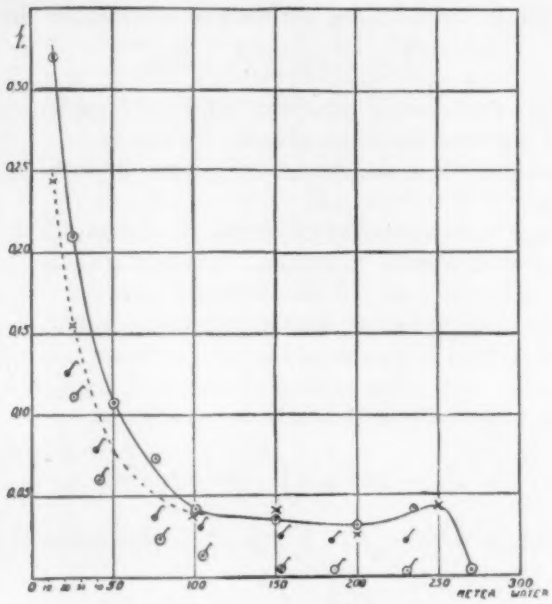
[1] W. F. G. Swann, *Phys. Rev.*, **43**, 945 (1933).

[2] W. F. G. Swann, *Phys. Rev.*, **44**, 943 (1933); J. Frank., Inst. **217**, 59 (1934). Also, W. F. G. Swann and A. Bramley. *Phys. Rev.*, **41**, 393 (1932).

[3] W. F. G. Swann, *Military Engineer*, Vol. XXVI, No. 146, 116–120, March–April, 1934. See in particular p. 120.

[4] J. Clay, *Physica*, **1**, 363 (1934).

FIG. 1.



what greater detail. Fig. 1 represents a reproduction of Clay's curve. The ordinates represent relative values of the ionization at the depths given by the abscissae. It will be observed that there is a hump at 250 meters followed by a relatively sharp fall to zero at about 270 meters.

STATEMENT OF HYPOTHESIS AND DEVELOPMENT OF CONSEQUENCES.

For simplicity we shall consider the case of a corpuscular radiation of definite energy of such amount that the corpuscles can travel a distance L in the medium before their energy becomes reduced to the point at which ordinary ionization commences. After the energy has fallen to the region characterized by ionization, we shall suppose that the particle completes its range in a further distance l, in which distance it ionizes in the ordinary manner. For convenience we shall consider the atmosphere as compressed to a layer of the density of the medium under consideration (water), and shall picture it as lying on top of that medium, and forming part of it. We shall denote by h the distance below the surface and by θ

the angle from the vertical. We shall suppose that the number of primary rays falling within the solid angle $\sin\theta d\theta d\varphi$ is

$$J = J_0 \cos^2\theta \sin\theta d\theta d\varphi,$$

$\cos^2\theta$ being the usually accepted empirical approximation to the result represented more exactly by the Gold formula, and φ being measured, of course, in the plane perpendicular to the vertical.

Consider an ionization chamber of volume V filled with gas at one atmosphere pressure. Then if q is the ionization per centimeter of path of the primary rays in the region of energy where they ionize, and if Q is the number of ions produced per second in the vessel by the primary rays, Q will be zero if $h > L + l$. Between the values of h given by $L + l$, and L the value of Q will be

$$Q_1 = 2\pi VqJ_0 \int_0^{\theta_1} \cos^2\theta \sin\theta d\theta,$$

where $\cos\theta_1 = h/(L + l)$. For $h < L$, the value of Q is

$$Q_2 = 2\pi VqJ_0 \int_{\theta_2}^{\theta_1} \cos^2\theta \sin\theta d\theta,$$

where $\cos\theta_1 = h/(L + l)$, $\cos\theta_2 = h/L$. Thus

$$Q = 0 \text{ for } h > L + l, \tag{1}$$

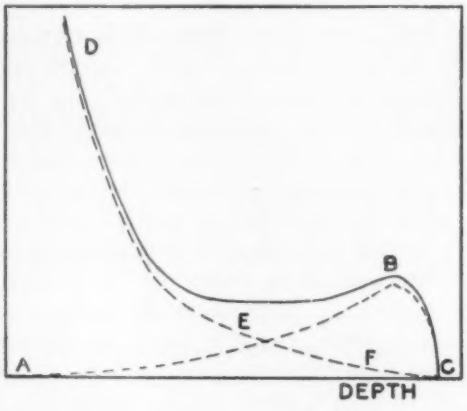
$$Q = Q_1 = \frac{2\pi}{3} VqJ_0\left[1 - \frac{h^3}{(L + l)^3}\right] \text{for } L < h < L + l, \tag{2}$$

$$Q = Q_2 = \frac{2\pi}{3} VqJ_0\left[\frac{h^3}{L^3} - \frac{h^3}{(L + l)^3}\right] \text{for } h < L. \tag{3}$$

We notice that for $h < L$, Q *increases* with increase of h, and proportionally to the cube. For $L < h < L + l$, Q decreases with increase of h, again in cubic fashion. The curve for Q plotted against h thus rises to a maximum (or rather to a highest value) at $h = L$, and then falls to zero at $h = L + l$. The general shape of the curve is such as is qualitatively indicated by the dotted curve of A, B, C of Fig. 2. To obtain the complete ionization in the vessel we must superpose upon this a curve which, according to our hypothesis would be produced by the showers generated by the primaries. If the

rate of production of showers decreases with decrease of energy of the rays, attaining a sensibly zero value by the time the energy has reached the value at which ionization begins, we may expect to obtain a curve such as that qualitatively represented by the dotted curve *D*, *E*, *F* of Fig. 2. The combination of these two curves to the full curve thus gives a result similar to that shown by Clay's graph. On the basis of our hypothesis we should associate the point at 250 meters depth in Clay's curve with the point *B* of Fig. 2, and, the point where Clay's curve cuts the horizontal axis at 270 meters should be associated with the point *C* of Fig. 2. The total range of ionization would thus correspond to a path of 20 meters in

FIG. 2.



water. Now according to the theoretical curves quoted by P. M. S. Blackett and G. P. S. Occhialini,[5] as obtained from the theoretical work of Bethe,[6] the energy loss, in ionization, per centimeter of path in water for rays of the order of 10^9 volts energy and of the electron type is about 2.5×10^6 volts per centimeter of path.[7] This gives 5×10^9 volts energy loss

[5] P. M. S. Blackett and G. P. S. Occhialini, *Proc. Roy. Soc.*, **A139**, 699 (1933).

[6] Bethe, *Ann. d. Physik; Zeits. f. Physik*, **76**, 293 (1932).

[7] Bethe's theory would of course become invalid for energies higher than those where ionization ceases; but, it would represent an approximation of the truth for lower energies.

in 20 meters of water. Anderson's experimental data on absorption lead to an energy loss of 8×10^9 volts in 20 meters of water. It is a significant fact that the calculations of A. Bramley and the writer, based on the writer's theory already cited, suggests 10^{10} as the energy at which ionization should cease. The figures are not of course intended to give more than orders of magnitude; but, viewed in this light, it is of considerable interest to note that the magnitudes 5×10^9 to 8×10^9 volts found from Clay's curve on the basis of the present ideas represents approximately an upper limit to the energies of rays observed in appreciable numbers in cloud chamber measurements.

On the basis of the foregoing ideas the ionization at 250 meters depth is representative of the value given by (2) with h put equal to L. This value is, approximately, $2\pi VqJ_0l/L$. On the other hand, the ionization which would be obtained at the surface of the medium if all of the primary rays were capable of ionizing there would be $2\pi VqJ_0/3$. Since our interpretation combined with Clay's curve gives l/L of the order of 20/280, we see that if all of the primary rays ionized at the surface of the medium, or let us say at the earth's surface, with the normal ionization efficiency, they would produce (1/3) $\times$ (1/14), i.e., about 5 times the ionization observed at 250 meters. But the ionization observed at 250 meters is only about one-twentieth of that observed at the earth's surface. Hence, it is necessary to assume that, at the earth's surface there are 20/5, i.e., 4 times as many rays as there are primaries. In other words, each ray is responsible for 4 shower rays at the earth's surface, and this number would be still further reduced if some of the surface ionization were caused by other ionization agencies, such as photons or their secondaries. The foregoing considerations render it possible that the showers concerned involve only one or two secondaries. In conclusion it may be added that we would hesitate to extend the ideas here involved in too great detail to the higher regions of the atmosphere. However, as appears from the foregoing, the main relevant facts are discussable in terms of a comparison of the ionization at the earth's surface with that at great depths.

A POSSIBLE EXPLANATION OF THE FREQUENCY DISTRIBUTION OF SIZES OF HOFFMANN STÖSSE.*

BY

C. G. MONTGOMERY

The cloud chamber photographs of Blackett and Occhialini, Anderson, and Locher [1] have brought to light the suggestion that Hoffmann Stösse may not originate in a single atom, but may arise from several atoms as the result of a primary cosmic ray acting through intermediaries. Each of these observers finds groups of ray tracks, apparently all formed simultaneously. These tracks are possibly produced by the particles which give rise to the bursts of ions observed in a pressure chamber. However, these tracks do not diverge from a common point, but seem, in many cases, to be formed in several groups, each group of tracks diverging from a separate point. The existence of these multiple centers has been attributed by Locher [1] to the action of neutrons which, coming from any one nuclear disintegration, serve to precipitate others. Experiments by W. F. G. Swann and the author are in progress at the present time for the purpose of testing this conclusion further and particularly to ascertain whether the size of a Stoss depends upon the amount of material involved.

Data showing the frequency of occurrence of Stösse of different sizes have been published by Steinke and Schindler, and by Messerschmidt [2] and similar data have been taken at the Bartol Foundation with an apparatus which has been previously described.[3] These data all show the surprising fact that although a greater portion of the Stösse is grouped around a definite size, Stösse ten times this size occur fairly often. The object of the present note is to show how the cooperation of several atoms in the production of a Stoss would give rise to such a frequency distribution of Stoss sizes as is observed.

* *The Physical Review*, January 1, 1934.

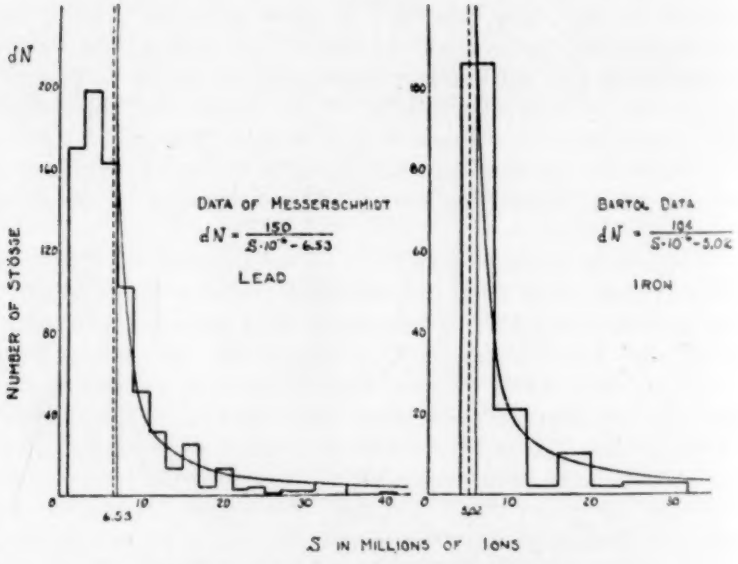
[1] P. M. S. Blackett and G. Occhialini, *Proc. Roy. Soc. Lond.*, **A139**, 699 (1933); C. D. Anderson, *Phys. Rev.*, **43**, 368 (1933); G. L. Locher, *Phys. Rev.*, **44**, 779 (1933).

[2] E. Steinke and H. Schindler, *Zeits. f. Physik*, **75**, 115 (1932); W. Messerschmidt, *Zeits. f. Physik*, **78**, 688 (1932).

[3] W. F. G. Swann and C. G. Montgomery, *Phys. Rev.*, **44**, 52 (1933).

Let us suppose we have a block of material placed over an ionization chamber and suppose a group of rays is formed near the top of the block. These rays will contain among them entities capable of producing other groups and such secondary groups will be produced within the block. If the ranges of the ionizing rays are greater than the thickness of the block, then rays from both the primary and secondary groups will reach the ionization chamber and be recorded. Thus, on the average, if the primary group is formed near the top of the block of material, the number of ionizing rays which penetrate the ionization chamber will be larger than if the primary group is formed near the bottom of the block. Then the recorded Stösse will consist of a whole range of sizes similar to the observed range.

FIG. 1.



Observed and computed distributions of sizes of Stösse.

We can put the matter into a more quantitative form and obtain a rather good agreement with the observed distribution curves if we make a few simplifying assumptions. Let us suppose that the primary group will produce p ions in the

chamber, and that p is independent of the position of the origin of the group. Also let us suppose that the rays of the primary group will produce a secondary group of size s ions, on the average, every a centimeters. Further let us suppose that each secondary group also produces groups of size s every a centimeters, and so forth. Then, if the primary group is formed at a distance r from the top of the block of material of thickness D, the size [4] of the resultant Stoss will be

$$S = p + s(2^{(D-r/a)} - 1). \tag{1}$$

Let us assume that the number of primary groups formed in the element of thickness dr is independent of r, then we can write $dN = kdr$ where k is a constant. From relation (1), we obtain

$$dS = -(\log 2/a)[S - (p - s)]dr$$

or

$$dr = -adS/\{\log 2[S - (p - s)]\}.$$

Then the form of the distribution curve will be given by

$$dN = -\frac{ak/\log 2}{S - (p - s)}dS = -\frac{A}{S - b}dS.$$

This depends on only two parameters, and we may fit it to the observed distribution curves. The data of Steinke and Schindler are unsuitable for consideration in the present connection since they give a distribution curve for the difference in size of Stösse occurring simultaneously in two chambers placed side by side. However, we can compare Messerschmidt's results and those obtained at the Bartol Foundation with this empirical formula. The accompanying curves show how well this elementary theory fits the observations. For Messerschmidt's data, we obtain $A = 75$, $b = 6.53 \times 10^6$ ions, and for the Bartol data $A = 26$, $b = 5.02 \times 10^6$ ions. b represents the difference in size of a primary and a secondary group, while $A = ak/\log 2$, where k is the total number

[4] The "2" in this expression results from the assumption that the number of groups doubles every "a" centimeters. As Dr. Swann has pointed out to the author, if the number of groups is derived by an integration process, the "2" becomes an "e."

of primary groups per centimeter. Since the observations do not extend to sufficiently small sizes, we can only set a lower limit to it. For the Bartol data, $D = 2.5$ cm. iron, $k > 59$ and hence $a < 0.3$ cm. For Messerschmidt's data, $D = 10$ cm. lead, $k > 81$ and $a < 0.6$ cm.

We see that the observed curves, in their middle range at least, are well represented by such a picture of the Stoss-forming process as is given here. The deviations at either end are certainly to be ascribed to the overly simplified picture used. An elaboration of the theory would involve a closer specification of the probabilities of formation of the secondary groups, rather than the assumption that they are all equal. Although this would improve the agreement, it would only tend to complicate the calculations and would add nothing to the picture of the mechanism. However, the agreement is certainly good enough to regard the model used as a fair approximation to what actually happens. It is to be noticed that the essential idea in the process is that all groups, whether primary or secondary, are capable of producing other groups. The application of the picture of a primary group producing secondary groups all along its path (S in this case would vary linearly with r) is not capable of giving a distribution curve of the type observed.

The real importance of this picture of the formation of Stösse lies in the predictions that can be made from it. First, there should be a lower limit to the sizes of Stösse, and this limit is the size of the primary group of rays. If an upper limit of size exists, it probably depends upon the energy of the primary cosmic ray. Second, the distribution curves of Stoss sizes will depend upon the thickness of the material from which the Stösse come: thicker materials should give larger Stösse. There should also be observed "transition" effects if there is a primary or secondary Stoss size characteristic of the material. The lower limit of the size should, however, be dependent only upon the last material through which the Stoss particles pass.

In conclusion, the author wishes to express his thanks to Dr. W. F. G. Swann for his helpful encouragement and discussion of the ideas involved here.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

HIGH-FREQUENCY RADIO FADEOUT ON OCTOBER 24, 1935.

In the magazine *Science* for October 11, Dr. J. H. Dellinger of the Bureau reported the occurrence of fadeouts of high-fequency radio signals on March 20, May 12, July 6, and August 30. It was pointed out that the phenomenon was semi-worldwide, involving high-frequency radio transmission over the illuminated half of the globe and not the dark half. The time intervals between the occurrences varied from a little over 53 to a little over 55 days. The next interval of this approximate length terminated during the period October 21 to 25. A fadeout of modified form is now reported as having occurred on October 24. While this was 55 days after August 30, undue importance should not be attached to the approximate 54-day cycle. Similar fadeouts may have occurred but have gone unobserved at times halfway between i.e., for each rotation of the sun.

The occurrence on October 24 was a wiping out of radio transmission above a certain frequency throughout the day in question. This obliteration of signals did not extend to as low values of frequency as in the previous cases, and was not as sudden, but it occurred under peculiar circumstances as regards sunspots and magnetic storms, and sheds new light on the relations of these phenomena. It is possible that one of the sudden fadeouts of the previously observed type also occurred; it was not observed in the United States, and whether it occurred elsewhere or at a time when no one was observing may never be known. The cause of all these phenomena is undoubtedly some eruption on the sun.

A remarkable increase in sunspot activity began on October 10, and this was accompanied by a general improvement in radio transmission on the higher frequencies. Amateurs and others found that they received excellent daytime signals on much higher frequencies than usual. By October 21 to

* Communicated by the Director.

23 the upper limit of frequency had reached the highest value ever observed at the Bureau. Then, for a single day, October 24, this was completely reversed. The upper limit of frequency on this one day dropped to half its value on the preceding days. On October 25 and succeeding days it returned to the high previous values. This was accompanied also by a remarkable change in the height of the upper ionized layer of the atmosphere which reflects radio waves. This height shot up to 290 miles on October 24 from a height of about 150 miles on the preceding and following days. Moreover, October 24 was a day of considerable magnetic disturbance. The radio effects were all at frequencies higher than those used for broadcasting. A technical report on this occurrence was published in the November issue of the *Physical Review*.

The significance of these phenomena lies in the definiteness of what happened. Scientists have long been puzzling over the connection between magnetic disturbances, sunspots, and radio transmission. Magnetic disturbances, sunspot activity, and poor high-frequency radio reception have been considered to go together, in general. There are many exceptions, and the October observations may help to work out this relation. They showed that in one respect at least high-frequency radio transmission was better as sunspot activity increased, and that it was suddenly impaired for a relatively short time. At the time of a radio fadeout, there is doubtless some eruption on the sun much more sudden than the growth of a sunspot, which abruptly changes the rate at which the sun sends certain waves or particles into the earth's atmosphere. Such eruptions also produce magnetic disturbances. There has hitherto been no way of identifying particular magnetic disturbances associated with such eruptions. The radio effects, on the other hand, are easily identified, and further study of them may furnish a means of closer insight into the mysteries of magnetic disturbances and other effects closely related to events on or in the sun.

INFRARED RADIATION FROM OTTO CYCLE ENGINE EXPLOSIONS.

A paper under the above title will appear in forthcoming issues of *Engineering* (London, England).

This paper contains a detailed account of the improved apparatus used at the Bureau in making measurements of radiant energy, to a wave-length of 11 microns, emitted by explosions in the cylinder of a small L-head engine running on benzole and on blends of benzole with gasoline.

Observations, made through five selective filters, are recorded: Normal and knocking engine flames; blast-torch flames of liquid fuels; blowpipe flames of hydrogen, carbon monoxide and city gas; the flame of gasoline burning on a wick; and a small black-body furnace heated to temperatures between 800° and 1,400° K.

For engine flames the results are presented in curves of dR/dt against crank angle, where R is the total radiation received by the measuring thermocouple up to time t from the beginning of an average cycle. A table is also included, giving the relative amounts of energy transmitted by the several filters from the various sources of radiation.

PROTECTION OF HIGH-STRENGTH ALUMINUM ALLOYS AGAINST CORROSION.

The commercial development of sheet material for building aircraft, consisting of a high-strength alloy sheet bearing a protective surface skin of pure aluminum, constituted one of the notable advances of the past decade in the aircraft-materials field. Following its first large-scale utilization, systematic periodic examinations have been made at the Bureau to determine the degree of reliability of this material under actual service conditions. The results of the latest examination confirm the early predictions based on laboratory experiments. Although the aluminum protective skin is not immune to corrosion, this very corrosion accomplishes a useful purpose. The protection afforded galvanized steel by the "sacrificial" corrosion of its zinc surface finds its counterpart in the protection of the underlying alloy by the aluminum. It has been observed that when, in certain spots, corrosion has entirely penetrated the aluminum coating, perforation of the sheet has not occurred, the electrolytic behavior of the aluminum coating being favorable to a lateral spreading of the corrosive attack, rather than to deep penetra-

tion. While definite data on the ultimate useful life of the material are not yet available, it is plainly evident that this combination is very dependable from the standpoint of corrosion resistance under all ordinary conditions.

INDEX OF REFRACTION OF SOME POTASH-SILICA GLASSES.

Continuing the Bureau's work on the relation between certain properties and the composition of glass, 86 glasses of the potash-silica series were made, annealed, analyzed, and the index of refraction measured. The composition of the glasses ranged from approximately 15 to 40 per cent. potash, silica being the only other constituent present. They were made from the purest obtainable potassium carbonate and powdered quartz and were melted in platinum.

The index of refraction (for sodium light) changed from 1.5019 at 37 per cent. potash to 1.4804 at 17 per cent. Although the actual refractivities of the potash-silica glasses are less than those of the corresponding soda-silica glasses (1.5076 and 1.4851) by approximately 0.005, it is interesting to note that the total change in each series is approximately the same (0.022).

If the refractivities of the potash glasses are plotted against their potash (or silica) content, it seems that the data can be represented by two straight lines intersecting at about 29 per cent. potash (71 per cent. silica), better than by a continuous curved line. These two straight lines may be represented by the equations:

$$N = 1.4676 + 0.00092K,$$
$$N = 1.4603 + 0.00118K',$$

in which N is the index of refraction of the glasses, K is a potash content greater than 29, and K' is less than 29 per cent.

It must be noted, however, that extrapolation of the K' equation to 100 per cent. silica ($K' = 0$) gives 1.4603 as the index of refraction of pure vitreous silica, a value 0.0016 greater than the measured value. This suggests another straight line somewhere between 85 and 100 per cent. silica, or necessitates some curvature in that range. That a straight

line might be anticipated is suggested by previous data on the soda-lime-silica glasses (reported in *B. S. J. Research*, **6**, 933 (1931) RP320), because extrapolation to 100 per cent. silica of the data in that report gives the proper value for the index of refraction of vitreous silica.

NATURE OF THE GLASS PHASE IN HEATED COMMON CLAYS.

A study has been made of the development and behavior of the glass phases in a glacial clay, an alluvial clay, and a shale when heated at various temperatures. The clays and shale were commercial raw materials used in the manufacture of face and common brick and red floor tile.

Shrinkage of the alluvial clay and shale specimens began with the formation of glassy bonds at cone 06. However, in the case of the glacial clay it was necessary to heat the specimens to cone 1 before the rather large quantity of dolomitic glass already formed became sufficiently fluid to cause shrinkage. The colors of the heated specimens were governed largely by changes which occurred in the glassy bonds during the heating process. The original yellow color of the iron-bearing clay grains in the unheated clays and shale became reddish-brown after heating to cone 08. Higher temperatures caused increasing solution of such grains, saturating the glass phase with iron compounds. Four kinds of artificial minerals crystallized from the saturated glassy bonds. Precipitation of a red mineral from the glass bonds was noted in all of the specimens heated to cone 06. Because of their minute size the optical properties of these red crystals have not been completely determined. The quantities of red crystals increased in the glassy bonds of the specimens of alluvial clay and shale with increasing temperature, reaching a maximum at cones 5 to 7. This was the temperature range of the development of the most intense red colors of the specimens. A decrease or entire disappearance of the red crystals was accompanied by a change of color of the specimens from red to gray or black, caused by the formation of a black glass. Factors causing the solution of red crystals were: Heating to cone 9 or more; reducing atmosphere; and the presence of glass of high line and magnesia content. The glacial clay

specimens containing a large amount of dolomite failed to develop this red color. Microscopical examination showed that the red crystals were somewhat dissolved at cone 06 and almost completely dissolved at higher temperatures, with the precipitation of an unidentified green birefringent mineral. Its presence in large quantities produced an olive green tint in the specimen heated to cone 1. The homogeneous glasses prepared by fusion of the clays and shale were black because of the high temperature required for fusing the materials and fining the resulting glasses. A green mineral resembling spinel crystallized from the glassy bonds in the alluvial clay and shale specimens heated to cones 8 to 9. Mullite was also found in these glasses.

Of the three glasses resulting from fusion of the three materials, that made from the alluvial clay contained the most silica, had the lowest refractive index and coefficient of expansion, and had the highest softening point. The properties and chemical composition of the glass resulting from fusion of the shale were intermediate between those resulting from the fusions of the alluvial and glacial clays.

THE SYSTEM: K_2O-PbO-SiO_2.

This supplements the report published in Technical News Bulletin 211 (November 1934). The additional study of this system indicates that it contains four ternary compounds having the molecular ratios 1 : 2 : 2, 1 : 4 : 8 (previously reported as 1 : 3 : 6) and 1 : 1 : 4, and 2 : 1 : 3, respectively, with the possibility of a fifth. The first, crystallizing as hexagonal plates with a melting point of 918° C. is uniaxial negative, has indices ω 1.93 ± 0.01, ϵ 1.72 ± 0.01, and the optic axis is perpendicular to the cleavage. The second, crystallizing as well defined fibres or lathes, melting at 779°, and resembling a short fibred asbestos when crushed, has indices ranging from 1.69 ± 0.01 to 1.79 ± 0.01, extinction is parallel, and the optic axis is parallel with the longitudinal axis. The third is positive biaxial, crystallizes as rectangular, platy granules of parallel extinction which melt at 757°; the optic angle is about 75° and the indices: α 1.590, β 1.612, γ 1.65. (All indices ± 0.005.) The fourth is platy with an

average index of approximately 1.67 and melts incongruently at 737° and is very unstable.

The index of refraction, linear thermal expansion to 300° C. and the softening temperature, of the first three compositions, as glasses, are respectively: 1.775, 0.46 per cent. and 395° C.; 1.712, 0.28 per cent., and 460° C.; and 1.606, 0.36 per cent., and 463° C. The 2 : 1 : 3 compound composition is very unstable as a glass.

Governmental Investigation of Rattlesnakes.—Offhand one would be inclined to link babies with rattles, but now biologists of the U. S. Department of Agriculture tell us that rattles are just what baby rattlesnakes do not have. Instead, a newborn rattler must be content with just a button—on the end of its tail. Only after twice shedding its skin, a few days after birth and about two months later, is the first ring of the rattle formed.

The power of the rattle seems dependent upon the fact that the last 7 or 8 of the snake's vertebræ early fuse into a solid bone, the "shaker," around which the rings of the rattle form. Normally one ring is added to the rattle every time the snake sheds its skin, which is usually three times a year. According to the biologists, a small number of rings is more an indication of a snake's tail-wagging proclivities than its youthfulness. In other words rings are shaken or broken off by the vigor of the tail's movements. What is more, it is believed that nature gave the snake his rattle not as a warning device, but to be used as a call or a challenge during the breeding season. However that may be, it does serve as a highly effective "keep off the grass" and saves the snakes a lot of bother.

C.

"It was while in his bath that Archimedes is said to have made the historic discovery that whenever a body is immersed in a fluid it is buoyed up with a force just equal to the weight of the fluid displaced."—T. A. Boyd, "Research."

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, DECEMBER 18, 1935.

The regular monthly meeting of The Franklin Institute was called to order at 8:15 o'clock by Mr. Henry Butler Allen, Director. Mr. Allen announced the death of Dr. Howard McClenahan, Secretary and former Director, which occurred on December 17th in Florida.

The Assistant Secretary announced that the minutes of the November meeting had been published in the December issue of the JOURNAL of the Institute, and if there were no objections or corrections they could be approved at this time. As there were no objections, the Chairman declared the minutes approved.

The Assistant Secretary reported the addition of twenty-five Institute members and one hundred and fifty-two Museum members since the last meeting.

The following nominations were made for officers and managers for the term beginning with January 1936:

President	*Board of Managers*
(to serve one year)	(to serve three years)
Nathan Hayward	Edward G. Budd
Vice-Presidents	Clarence A. Hall
(to serve one year)	George A. Hoadley
Henry Howson	A. Atwater Kent
Walton Forstall	Richard W. Lloyd
W. Chattin Wetherill	O. J. Matthews
Samuel S. Fels	George W. Pepper
Treasurer	James S. Rogers
(to serve one year)	(to serve one year)
Benjamin Franklin	Irenee DuPont

The Chairman called for other nominations, but none being presented, he declared the nominations closed.

Mention was also made of the Christmas Week Lectures which will be held on December 26, 27 and 28, and the special demonstration in the planetarium "The Heavens Declare" which will be continued for another week.

The Chairman then introduced Dr. Detlev W. Bronk, Director, Eldridge R. Johnson Foundation for Research in Medical Physics, Graduate School of Medicine, University of Pennsylvania. After a brief tribute to the late Dr. McClenahan, Dr. Bronk introduced Dr. Robert H. Gault, Director General, American Institute for the Deaf Blind, Evanston, Illinois, who addressed the meeting on "Recent Developments in Vibro-Tactile Experiments."

The speaker after referring to the passing of Dr. McClenahan gave an account of the progress in his field since his last lecture at the Institute.[1] His present

[1] J. F. I., **209**, 437.

paper covered excitation of the organs of touch and vibration by vibratory stimuli such as forms of speech and music. Stimuli are transmitted through a microphone, highly specialized amplifier and vibrating unit to a finger resting upon the latter. Attempt to develop an amplifier that will enable one to feel in the finger, all essential frequencies or pitches in the same relations of intensity as they are received by the normal ear without artificial amplification. The effects of masking or interference of frequencies—other conditions (pressure, area) of optimal stimulation. A study of conditioned reactions and of action currents in lower animals, with and without hearing; with and without intact posterior spinal cord tract, (*a*) to determine functional relations among tactual, vibratory and auditory senses, and (*b*) to attempt an isolation of the vibratory sense mechanism.

The subject was illustrated by lantern slides. After a brief discussion, Dr. Bronk thanked the speaker for his interesting lecture.

At the close of the meeting, Mr. Allen introduced Dr. James Barnes, Associate Director, who then demonstrated his magic Christmas tree which is one of the special attractions of the holiday season. The tree is sprayed with luminous and phosphorescent chemicals and is illuminated alternately by ordinary light and by ultra-violet light. The effect is very striking.

The meeting adjourned at ten o'clock.

ALFRED RIGLING,
Assistant Secretary.

RESOLUTION PASSED BY THE BOARD OF MANAGERS ON THE OCCASION OF THE DEATH OF MR. ROBERT W. LESLEY.

In the death of Mr. Robert W. Lesley, member of the Board of Managers, the Institute has lost one of its most faithful friends and able supporters. Mr. Lesley became a member of the Institute on April 8, 1908. He was elected to the Board of Managers in 1913 and served continuously since that time. He was an important member of the Committee on Membership and acted as its chairman for many years. He also served with distinction on the Committee on Endowment.

A deep sense of personal loss is felt by every member of the Board in the death of a friend and co-worker whose qualities of heart and mind endeared him to all, therefore be it

Resolved: That the Board of Managers of The Franklin Institute records with profound sorrow the death on November 10, 1935, of its esteemed and distinguished member, Mr. Robert W. Lesley, and be it

Resolved Further: That the sympathy of the Board be extended to Mrs. Lesley in her great bereavement, and be it

Resolved Further: That a copy of the above preambles and resolutions be sent to Mrs. Lesley and a copy be published in the JOURNAL.

November 20, 1935.

RESOLUTION PASSED BY THE BOARD OF MANAGERS ON THE OCCASION OF THE DEATH OF MR. CHARLES H. EWING.

The Board of Managers of The Franklin Institute, sensible of the loss which its membership has sustained through the untimely death of Charles H. Ewing, on December 8th, unanimously resolves that there be recorded in its minutes this present memorial of the faithful service rendered by Charles H. Ewing, as a member of this body, in recognition of his efficient collaboration and in appreciation of the sterling qualities of his genial personality.

The Board further resolves that this minute be published in the JOURNAL of the Institute and a copy thereof be transmitted to the family of the deceased.

December 18, 1935.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, December 11, 1935.)

HALL OF THE COMMITTEE,
PHILADELPHIA, DECEMBER 11, 1935.

MR. CHARLES H. MASLAND, 2D, *in the Chair.*

The following reports were presented for final action:

No. 2975: Gyroscopic Blind Flying Instruments.

This report recommended the award of the Edward Longstreth Medal to Elmer A. Sperry, Jr., of Brooklyn, New York, "In consideration of his initiative and for his work in the development of blind flying instruments employing gyroscopic principles, which development includes the gyroscopic horizon, directional gyro and automatic airplane pilot."

No. 3002: Planamilling and Planathreading.

This report recommended the award of the Edward Longstreth Medal to Mr. Peter P-G. Hall, of Philadelphia, "In consideration of his invention and development of machine and cutters for planetary milling and threading."

The following report was presented for first reading:

No. 2990: The Determination of Gravity at Sea.

GEO. A. HOADLEY,
Secretary to the Committee.

LIBRARY NOTES.

RECENT ADDITIONS.

AGG, THOMAS R., AND WALTER L. FOSTER. The Preparation of Engineering Reports. First Edition. 1935.

City History Society of Philadelphia. Philadelphia History. Volume 2. No date.

CLAYTON, WILLIAM. The Theory of Emulsions and Their Technical Treatment. Third Edition. 1935.

Columbia Encyclopedia in One Volume. Compiled and Edited at Columbia University, Clarke F. Ansley, Editor-in-Chief. 1935.

DAWSON, T. R., AND B. D. PORRITT. Rubber. A Technical Handbook Produced by the Coöperation of the Rubber Growers' Association, Inc. and the Research Association of British Rubber Manufacturers. 1935.

DURAND, WILLIAM FREDERICK. Aerodynamic Theory. Volume 5, 1935.

GUILLEMIN, ERNST A. Communication Networks. Volume 2. The Classical Theory of Long Lines, Filters and Related Networks. 1935.

HARRISON, H. H., AND T. P. PREIST. Automatic Street Traffic Signalling. (Apparatus and Methods.) 1934.

HENNEY, KEITH, Editor. The Radio Engineering Handbook. Second Edition. 1935.

Jahresbericht über die Leistungen der chemischen Technologie für das Jahr 1934, 80 Jahrgang, 2 Abteilung: organischer Teil. 1935.

JAMESON, ALEX. H. Advanced Surveying. A Text-book for Students. 1934.

KANE, JOSEPH NATHAN. More First Facts. A Record of First Happenings, Discoveries and Inventions in the United States. A Supplement to Famous First Facts. 1935.

KAUSCH, OSCAR. Das Kieselsäuregel und die Bleicherden. Ergänzungsband. 1935.

KELLY, HAROLD CALEB. Modern Methods in Watch Adjusting. 1933.

KOHLRAUSCH, F. Praktische Physik zum Gebrauch für Unterricht, Forschung und Technik. Siebzehnte vollständig neu bearbeitete Auflage—Herausgegeben von F. Henning. 1935.

MACKROW, CLEMENT, AND LLOYD WOOLLARD. The Naval Architect's and Shipbuilder's Pocket-Book of Formulæ, Rules, and Tables and Marine Engineer's and Surveyor's Handy Book of Reference. Thirteenth Edition. 1931.

Metals and Alloys. Cumulative Index of Metallurgical Abstracts Published in Volumes 3–5 of Metals and Alloys. January 1932–December 1934. 1935.

Organic Syntheses: an Annual Publication of Satisfactory Methods for the Preparation of Organic Chemicals. Volumes 14 and 15. 1934–1935.

PAGE, LEIGH. Introduction to Theoretical Physics. Second Edition. 1935.

PAPP, DESIDERIUS. Creation's Doom. 1934.

Physical Society. Reports on Progress in Physics. 1934.

REED, BRIAN. Diesel Locomotives and Railcars. No date.

RICHTER, O., AND R. v. VOSS. Bauelemente der Feinmechanik. 1929.

Royal Society of Edinburgh. Transactions. Volume 58. 1934–1935.

SAUVEUR, ALBERT. The Metallography and Heat Treatment of Iron and Steel. Fourth Edition. 1935.

SHRINER, RALPH L., AND REYNOLD C. FUSON. The Systematic Identification of Organic Compounds. A Laboratory Manual. 1935.

Technik Geschichte. Beiträge zur Geschichte der Technik und Industrie. Band 24, 1935.

TURNER, H. COBDEN, AND E. H. W. BANNER. Electrical Measurements in Principle and Practice. 1935.

WILLIAMS, ROBERT S., AND VICTOR O. HOMERBERG. Principles of Metallography. Third Edition. 1935. International Chemical Series.

WOLF, A. A History of Science, Technology, and Philosophy in the 16th and 17th Centuries. 1935.

WOOD, KARL D. Technical Aerodynamics. First Edition. 1935.

WOODRUFF, E. B., AND H. B. LAMMERS. Steam Plant Operation. First Edition. 1935.

YAMADA, NAKABA. GHENKŌ The Mongol Invasion of Japan. London, 1916.

THE FRANKLIN INSTITUTE.

CERTIFIED FINANCIAL STATEMENTS

for the Year ended September 30, 1935.

December 12, 1935.

To the Board of Managers of
The Franklin Institute,
Philadelphia.

We have examined the accounts of The Franklin Institute for the year ended September 30, 1935. In connection therewith, we examined or tested the accounting records of the Institute and other supporting evidence, but we did not make a detailed audit of the transactions. The real estate, buildings and equipment and investments are stated at cost or appraised values at dates of acquisition.

Subject to the foregoing, the annexed financial statements, in our opinion, fairly present, in accordance with accepted principles of accounting consistently maintained by the Institute during the year under review, the financial position of The Franklin Institute, at September 30, 1935, and the results of operations for the year ended that date.

(Signed) LYBRAND, ROSS BROS. & MONTGOMERY.

THE FRANKLIN INSTITUTE.

BALANCE SHEET, SEPTEMBER 30, 1935.

Assets.

Cash in banks and on hand (not including cash in endowment trust funds)		$48,620.02
Accounts receivable for memberships, subscriptions, etc.		2,094.64
Materials and supplies, at cost		4,258.19
Real estate, buildings and equipment, at cost, not including exhibits loaned and donated		4,033,137.96
		$4,088,110.81
Endowment fund investments, cash, etc.:		
Investments, at cost or the appraised values at the dates of acquisition	$2,601,605.53	
(Investment securities of the General Endowment Fund having a value of $69,742.50 at market quotations as of September 30, 1935, pledged as collateral for notes payable, see contra)		
Deposit in closed bank, less reserve	85,000.00	
Cash:		
Uninvested principal	13,700.73	
Unexpended income	6,085.46	
		2,706,391.72
		$6,794,502.53

Liabilities.

Notes payable		$76,000.00
(Investment securities of the General Endowment Fund having a value of $69,742.50 at market quotations as of September 30, 1935, are pledged as collateral for this loan, see contra)		
Accounts payable		7,532.62
		83,532.62
Deferred income from dues, etc.		1,909.29
Contributed funds used for buildings, equipment, etc		3,816,744.71
Stock outstanding:		
First class	$13,240.00	
Second class	70.00	
		13,310.00
General Fund account, as annexed		172,614.19
		$4,088,110.81
Endowment funds:		
Principal	2,700,306.26	
Unexpended income	6,085.46	
		2,706,391.72
		$6,794,502.53

GENERAL FUND ACCOUNT

for the year ended September 30, 1935.

Balance, October 1, 1934		$153,752.62
Add:		
Members reinstated	$15.00	
Amount withdrawn from the Museum Reserve Fund Principal for capital and operating expenditures	103,000.00	
		103,015.00
		$256,767.62
Deduct deficit for the year ended September 30, 1935		84,153.43
Balance, September 30, 1935		$172,614.19

INCOME AND EXPENSE ACCOUNT

for the year ended September 30, 1935.

Income.

Dues, initiation fees, etc	$14,658.50
Less dues uncollected, prior years	651.50
	14,007.00
Admissions to museum and planetarium, sale of guide books, etc	82,541.75
Subscriptions to publications and advertising	7,371.71
Miscellaneous income	8,758.17
	112,678.63
Income from trust fund investments, etc	125,273.65
	$237,952.28

Expenses.

	Salaries and Wages	Other	
Building operation and maintenance	$44,653.15	$36,080.24	
Library	15,787.77	6,162.77	
Meetings	—	4,006.77	
Office and general	44,879.70	10,508.03	
Machine shop	1,321.35	289.43	
Museum	95,295.68	37,700.99	
Publications	—	12,571.85	
Science and The Arts	—	3,871.14	
Miscellaneous	—	5,556.76	
Interest and discount	—	3,420.08	
	$201,937.65	$120,168.06	
			322,105.71
Deficit for the year			$84,153.43

SUMMARY OF CHANGES IN ENDOWMENT FUNDS

for the year ended September 30, 1935.

Balances, October 1, 1934		$2,687,420.66
Add:		
Estimated value of claim against the Franklin Trust Company, transferred from Benjamin Franklin Memorial, Inc., account	$85,000.00	
Increase in John G. Meigs Bequest, representing one-half interest in real estate at 1408 Spruce St., Philadelphia, and other miscellaneous adjustments not previously reflected in accounts	32,628.83	
Profit on sale of investments	3,130.00	
Amount received for life membership	300.00	
Miscellaneous	28.91	
		121,087.74
		$2,808,508.40
Deduct:		
Losses on sale of investments	2,869.67	
Amount withdrawn from the Museum Reserve Fund for capital and operating expenditures, credited to General Fund Account	103,000.00	
Amount received as a distribution from principal of the John G. Meigs Bequest, credited to John G. Meigs Memorial Fund (income account)	2,332.47	
		108,202.14
Balances, September 30, 1935		$2,700,306.26

CONTRIBUTED FUNDS RECEIVED FROM BENJAMIN FRANKLIN MEMORIAL, INC.

for the period from September 30, 1930, to September 30, 1935, and disposition thereof.

Receipts from Benjamin Franklin Memorial, Inc.:		
To January 17, 1935, inclusive	$4,425,087.61	
Subsequent to January 17, 1935	24,884.29	
		$4,449,971.90
Deduct:		
Transfers to Museum Endowment Fund and other funds incident to operation of the museum	$280,930.84	

Estimated loss on uncollected balances aggregating $269,025.37, on deposit with Franklin Trust Company, in hands of the Banking Department of the State of Pennsylvania.....	184,025.37	
Transfers to General Fund to cover a portion of the costs of operation of the Museum for the three years ended September 30, 1934.....	168,270.98	
		633,227.19
Balance, September 30, 1935.....		$3,816,744.71

THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

CERTIFIED FINANCIAL STATEMENTS

for the Year ended September 30, 1935.

December 12, 1935.

To the Board of Managers of
The Franklin Institute,
Philadelphia.

We have examined the accounts of The Bartol Research Foundation of The Franklin Institute for the year ended September 30, 1935. In connection therewith, we examined or tested the accounting records of the Foundation and other supporting evidence, but we did not make a detailed audit of the transactions. The building, which is located on the property of Swarthmore College, and the equipment are stated at cost and the investments at cost or appraised values at dates of acquisition.

Subject to the foregoing, the annexed financial statements, in our opinion, fairly present in accordance with accepted principles of accounting consistently maintained by the Foundation during the year under review, the financial position of The Bartol Research Foundation of The Franklin Institute at September 30, 1935, and the results of operations for the year ended that date.

(Signed) LYBRAND, ROSS BROS. & MONTGOMERY.

THE BARTOL RESEARCH FOUNDATION OF THE FRANKLIN INSTITUTE.

BALANCE SHEET, SEPTEMBER 30, 1935.

Assets.

Cash:			
In bank and on hand, general fund		$821.43	
Unexpended income:			
Henry W. Bartol Bequest	$6,130.03		
Investment of unexpended income fund	15,274.24	21,404.27	
			$22,225.70
Investments of unexpended income fund			189,254.02
Building and equipment, at cost:			
Laboratory building		226,591.05	
Furniture and fixtures		14,874.93	
Equipment:			
Laboratory	$81,591.62		
Less allowance for depreciation	13,634.88	67,956.74	
Machine shop	16,831.75		
Less allowance for depreciation	2,168.51	14,663.24	
Office		2,891.37	
Library		1,057.65	328,034.98
			$539,514.70

Investments (at cost or appraised values at dates of acquisition) and cash of principal of trust funds:

	Investments.	Cash.	
Henry W. Bartol Bequest	$1,307,015.12	$3,512.00	
Pension fund	65,338.36	2,874.99	
	$1,372,353.48	$6,386.99	
			1,378,740.47
			$1,918,255.17

Collateral Trusts.

Cash:			
Uninvested principal	$43,739.53		
Undistributed income	2,809.01	$46,548.54	
Investments:			
Helene Bonor Bartol Trust	278,426.67		
Lucy Cheyney Farr Trust	145,657.03		
Katherine de Monclos Trust	144,501.19	568,584.89	
			615,133.43
			$2,533,388.60

Liabilities.

Accounts payable		$2,071.17
General Fund account:		
Balance, October 1, 1934	$529,396.03	
Less adjustment applicable to prior year	185.45	
Adjusted balance, October 1, 1934	$529,210.58	
Excess of income over expenses for the year ended September 30, 1935, as annexed	8,232.95	
		537,443.53
		$539,514.70
Endowment Funds:		
Henry W. Bartol Bequest	1,310,527.12	
Pension fund	68,213.35	
		1,378,740.47
		$1,918,255.17

Collateral Trusts.

Principal:			
Helene Bonor Bartol Trust	$306,398.00		
Lucy Cheyney Farr Trust	153,051.78		
Katherine de Monclos Trust	152,874.64		
		612,324.42	
Undistributed income		2,809.01	
			615,133.43
			$2,533,388.60

INCOME AND EXPENSE ACCOUNT
for the year ended September 30, 1935.

Income.

Income received from investments		$61,769.64
Other income:		
Contribution from American Philosophical Society for salaries of research professors	$2,250.00	
Contribution from National Geographic Society for loss sustained in stratosphere experiments in August, 1934	736.51	
Profit on sale of income investments	1,825.89	
		4,812.40
		$66,582.04

Expenses.

	Salaries and Wages.	Other.	
Building operation and maintenance	$1,500.00	$3,050.93	
Library	—	847.81	
Office and general	13,845.97	2,103.17	
Laboratory and machine shop	25,888.16	4,189.49*	
Publications, reprints	—	196.19	
Traveling expense	—	650.47	
Miscellaneous	—	6,000.50	
Loss on sale of laboratory equipment	—	76.40	
	$41,234.13	$17,114.96	
			$58,349.09
Excess of income over expenses for the year, transferred to General Fund Account			$8,232.95

* Includes provision of $949.20 for depreciation of laboratory equipment.

BOOK REVIEWS.

F. KOHLRAUSCH'S PRAKTISCHE PHYSIK, SIEBZEHNTE VOLLSTÄNDIG NEU BEARBEITETE AUFLAGE, Herausgegeben von F. Hennig. 958 pages, illustrations, 16 × 23.5 cms. Leipzig und Berlin, B. G. Teubner, 1935. Price 32 marks.

Due to the ever widening of man's knowledge of physical laws, physics is entering more and more into the lives of all of us. It is worthy of note that the degree of rapidity with which newer viewpoints are brought forth is challenging, so to speak, the writers of physics textbooks, for it is essential that texts on this basic subject be as up to date as possible. Not only this, but it is of paramount importance that the new texts present the subject in a continuously more appealing manner as more knowledge comes to light. That physics is one of the foundations of all science is unquestioned.

It is therefore with pleasure that we welcome to technical literature a new edition of the book that undoubtedly through its many earlier editions has been a basic book for a large number of scientific men of today. The new edition of "Praktische Physik" embodies a clear presentation of the fundamentals and modern knowledge of the subject. The work was made possible through the coöperation of eighteen men, all recognized authorities.

The book is constructed in six parts, each carefully planned and arranged in logical order. It begins with general matter relating to physical measurements and proceeds through mechanics, heat, optics, electricity and magnetism, to energy and quantities. Throughout emphasis is laid and extreme care is practiced on the fundamentals of each topic treated, particularly on those topics in which changes have been or possibly will be made. Notable among these are the parts devoted to electricity and the quantum. Those who are familiar with the previous editions are well acquainted with the thoroughness of treatment. This has been carried forward in this edition. Useful tables have been added in the

section provided for tables in the back of the book and there are 512 illustrations to assist in absorbing the text.

This book is outstanding for its clarity and is a modern presentation of the subject. It can be recommended to students as a text and to the research worker and practical physicist as a useful reference work.

R. H. OPPERMANN.

CHEMICAL ENGINEERING CATALOG—1935, Twentieth Annual Edition, The Process Industries' Catalog of Collected, Condensed and Standardized Data on Equipment, Machinery, Laboratory Supplies, Etc. 863 pages, 21 × 28.5 cms. New York, Reinhold Publishing Corporation, 1935.

The Twentieth Annual Edition now reposes upon the shelves of chemical libraries both academic and industrial. Unquestionably, it holds a position within easy reach of the executive and the engineer while its 1934 predecessor is being eagerly examined by chemical engineering students in the leading universities and technical schools.

Certainly, the Committee has not been idle during the year that has passed. The 1935 Catalog shows an increase of more than one hundred pages over the previous edition. Part of the increase is caused by a decision to include complete catalogs prepared individually by the firms concerned. However, the Committee has held to its principle of restricting the copy to actual technical data and omitting the usual advertising occupied with extolling the virtues of the particular product.

The arrangement of material is very much the same as before. The Information Bureau Service remains free to Catalog subscribers. A list of these follows and precedes the Trade Name Index—the latter being very helpful at times. Next comes the "piece de resistance"—the Classified Index of Equipment and Supplies which ushers in the various individual subscriber catalogs alphabetically arranged. The Industrial Chemicals and Raw Materials' list gives the supplier of each item as does also the Laboratory and Reagent Chemicals roster. The physical properties are supplied for many of the chemicals listed in the catalogs of the chemical manufacturers and are most welcome. The Technical and Scientific Book Section, which has been revised and brought up-to-date, is claimed to be the most complete bibliography of chemical technology in existence.

T. K. CLEVELAND.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 522, The Drag of Airplane Wheels, Wheel Fairings, and Landing Gears—III, by William H. Herrnstein, Jr., and David Biermann. 11 pages, illustrations, 20 × 26 cms. Washington, Superintendent of Documents, 1935. Price 10 cents.

The tests reported in this paper conclude the investigation of landing-gear drag that has been carried out in the N. A. C. A. 20-foot wind tunnel. They supplement earlier tests (reported in Technical Report No. 485) made with full-scale dummy wheels, wheel fairings, and landing gears intended for airplanes of 3,000 pounds gross weight and include tests of tail wheels and tail skids.

For airplanes of this weight classification the results indicate that the drag of a landing gear having slight wheel-strut interference will be materially less when

equipped with the proper size of streamline wheels than when furnished with low-pressure wheels. The drag of a cantilever landing gear is as low when equipped with the proper size of streamline wheels as when equipped with low-pressure wheels and the best type of wheel fairing.

Two of the landing gears tested combine, to a high degree, the structural advantages of the tripod types with the low drag of the full cantilever types.

The drag of a conventional tripod landing gear with streamline wheels can be reduced about 39 per cent. by careful fairing of all strut intersections.

Expanding fillets are useful in reducing landing-gear drag, especially on landing gears that are attached to wings.

The drags of tail-wheel units and tail skids are, even in the worst case, almost negligible.

Report No. 536, Wind Tunnel Tests of a 10-Foot-Diameter Gyroplane Rotor, by John B. Wheatley and Carlton Bioletti. 10 pages, illustrations, diagrams, 20 × 26 cms. Washington, Superintendent of Documents, 1935. Price 5 cents.

This paper presents the results of wind-tunnel tests on a model gyroplane rotor 10 feet in diameter. The rotor blades had zero sweepback and zero offset; the hub contained a feathering mechanism that provided control of the rotor rolling moment, but not of the pitching moment. The rotor was tested with 4 blades and with 2 blades. The entire useful range of pitch settings and tip-speed ratios was investigated including the phase of operation in which the rotor turned very slowly, or idled.

The results afford valuable information concerning the influences of pitch setting, solidity, and feathering angle upon the rotor characteristics. The feathering control appeared to be satisfactory in the normal flying range but showed a marked decrease in effectiveness at very low tip-speed ratios. A feathering angle considerably greater than the 10° that was provided was required at high tip-speed ratios and high pitch settings to obtain zero rolling moment. Unfortunately, because the rotor hub was disproportionately large, the measured lift-drag ratios are considered to be inexact.

Report No. 539, Investigation of Full-Scale Split Trailing-Edge Wind Flaps with Various Chords and Hinge Locations, by Rudolf Wallace. 26 pages, illustrations, tables, diagrams, 20 × 26 cms. Washington, Superintendent of Documents, 1935. Price 5 cents.

An investigation was conducted in the N. A. C. A. full-scale wind tunnel on a small parasol monoplane equipped with three different split trailing-edge wing flaps. The object of the investigation was to determine and correlate data on the characteristics of the airplane and flaps as affected by variation in flap chord, flap deflection, and flap location along the wing chord. The chords of the flaps were 10, 20, and 30 per cent. of the wing chord and each flap was tested at deflections from 0° to 75° when located successively at 68, 80, and 88.8 per cent. of the wing chord aft of the leading edge. The investigation included force tests, pressure-distribution tests, and downwash surveys. The results give the lift, the drag, and the pitching-moment characteristics of the airplane, the flap forces and moments, the pressure distribution over the flaps and wing at one section, and the downwash characteristics of the flap and wing combinations.

An increase in flap chord or distance of the flap from the leading edge of the wing increased the lift of the airplane but had an adverse effect on the wing pitching moment. The L/D ratio of the airplane decreased with increase in flap deflection or flap chord. Flap normal-force coefficients were primarily a function of flap deflection and were relatively independent of flap chord, hinge-axis location, and airplane attitude. The location of the flap center of pressure in percentage of flap chord aft of the hinge axis remained practically constant irrespective of airplane attitude and of flap deflection, chord, or location. Flap hinge-moment coefficients varied with a power of flap chord greater than the square so that with regard to hinge moments narrow flaps were the most efficient in producing a given increase in lift.

PUBLICATIONS RECEIVED.

The Eruption of Mt. Pelée, 1929–1932, by Frank A. Perret. 125 pages, plates, 23 × 29 cms. Washington, Carnegie Institution, 1935.

A Treatise on Heat (Including Kinetic Theory of Gases, Thermodynamics and Recent Advance in Statistical Thermodynamics). Being the second and revised edition of A Text Book of Heat, by M. N. Saha and B. N. Srivastava, second edition. 815 pages, illustrations, plates, 17 × 25 cms. Allahabad and Calcutta, The Indian Press, Ltd., 1935.

Photo-Electric and Selenium Cells, their Operation, Construction and Uses, by T. J. Fielding. 140 pages, illustrations, 12 × 20 cms. Pittsburgh, Instruments Publishing Company, 1935. Price $1.75.

Le Champ électromagnétique, par Marc Jouguet. 220 pages, illustrations, 11 × 17 cms. Paris, Librairie Armand Colin, 1935. Price 10fr. 50.

Répertoire International des Centres de Documentation chimique. 115 pages, 21 × 30 cms. Paris. Office International de Chimie. 1935.

U. S. Bureau of Mines. Monograph 6, Flow of Natural Gas Through High-pressure Transmission Lines. A joint report by T. W. Johnson and W. B. Berwald. 120 pages, diagrams, 15 × 23 cms. Baltimore, Baltimore Press.

Statistical Appendix to Minerals Yearbook, 1934. 434 pages, 15 × 23 cms. Washington, Government Printing Office, 1935. Price $1.00.

Minerals Yearbook, 1935. 1293 pages, 15 × 23 cms. Washington, Government Printing Office, 1935. Price $2.00.

National Advisory Committee for Aeronautics, Twentieth Annual Report, 1934, including Technical Reports Nos. 475 to 507. 649 pages, illustrations, diagrams, 24 × 30 cms. Washington, Government Printing Office, 1935. Price $2.75.

Technical Notes, No. 544, An Application of the Von Kármán-Millikan Laminar Boundary-Layer Theory and Comparison with Experiment by Albert E. von Doenhoff. 11 pages, figures, 20 × 26 cms. Washington, Committee, 1935. No. 545, Tank Tests of a Model of a Flying-Boat Hull Having a Longitudinally Concave Planing Bottom by J. B. Parkinsor. 10 pages, figures, 20 × 26 cms. Washington, Committee, 1935. No. 546, Comparative Tests of Pitot-Static Tubes by Kenneth G. Merriam and Ellis R. Spaulding. 37 pages, figures, tables, 20 × 26 cms. Washington, Committee, 1935. No. 547, Development of

the N. A. C. A. Slot-Lip Aileron by Fred E. Weick and Joseph A. Shortal. 10 pages, figures, 20 × 26 cms. Washington, Committee, 1935. No. 248, Flight Tests of a Balanced Split Flat with Particular Reference to Rapid Operation. 14 pages, figures, table, 20 × 26 cms. Washington, Committee, 1935.

The Nucleus of the Atom and its Structure. Sigma xi Symposium, Ohio State University, 1935. 104 pages, illustrations, plates, 17 × 25 cms. Columbus, Ohio State University. 1935. Price $1.00.

Canada Department of Mines, Limestones of Canada, Their Occurrence and Characteristics, Part III, Quebec by M. F. Goudge. 274 pages, illustrations, tables, maps, 16.5 × 25 cms. Ottawa, King's Printer, 1935. Price 50 cents.

Gold in Canada, 1935, by A. H. A. Robinson. 127 pages, tables 16.5 × 25 cms. Ottawa, King's Printer, 1935. Price 25 cents.

Canada Dominion Bureau of Statistics, Agricultural Branch, Report on the Grain Trade of Canada, 1934. 222 pages, diagrams, tables, 16.5 × 25 cms. Ottawa, King's Printer, 1935. Price 50 cents.

Forestory Branch, Census of Industry, Paper-Using Industries in Canada, 1933. 98 pages, tables, 16.5 × 25 cms. Ottawa, King's Printer, 1935. Price 25 cents.

Bell Telephone Laboratories, Monographs: B-873, An Unattended Ultra-Short-Wave Radio Telephone System by N. F. Schlaack and F. A. Polkinghorn. 11 pages, illustrations. B-880, A Rapid Method for the Determination of Sulfur in Ferromagnetic Alloys by Beverly L. Clarke, L. A. Wooten, C. H. Pottenger. 6 pages. B-881, The Preparation of Iron and Steel Specimens for Microscopic Investigations by Francis F. Lucas. 20 pages, illustrations. B-882, The Generation of Stibine by Storage Batteries by H. E. Haring and K. G. Compton. 10 pages, illustrations, diagrams. B-883, Behavior of Lead, Lead-Antimony and Lead-Calcium Alloys in Storage Cells by H. E. Haring and U. B. Thomas. 15 pages, illustration, diagrams. B-884, Physical and Metallurgical Properties of Lead-Calcium Alloys for Storage Cells by Earle E. Schumacher and G. S. Phipps. 8 pages, illustrations, diagrams. B-885, Electrical Resistance Measurements for Control of Alloy Composition by Earle E. Schumacher and Lawrence Ferguson. 8 pages, illustrations, diagram. 7 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1935.

CURRENT TOPICS.

Electric Furnaces with Carbon Radiator.—HENRI GEORGE, of the Saint-Gobain Company, France, describes in *Electrical Engineering*, Vol. 54, No. 11, a type of electric furnace for application to metallurgy and to operations at very high temperatures. The essential feature of the furnace is a carbon radiator mounted within the furnace chamber and raised to a very high temperature by the current flowing through it. This radiator can be reduced to a simple graphite rod, which allows high current densities (200 to 500 amperes per square centimeter) to be used, and which radiates freely to the charge and to the walls. From the electrical viewpoint the general properties are those of a resistance furnace; there is constant load for each value of the supply voltage and absence of any inductance. From the thermal viewpoint, the use of graphite resistors makes it possible to attain very high temperatures (3000 deg. C. in special furnaces) or to build very flexible furnaces, the power rating of which may be quite considerable. Mr. George describes a small kw. furnace for melting steel in which the power consumption was 0.8 kwh. per kilogram for steel cast at 1650° C. and 0.5 and 0.25 kwh. per kilogram for cast iron and bronze, respectively. Several interesting features are embodied in the mechanical construction of this type furnace, as well as in the electrical construction. The latter are made important by the necessity of bringing large currents to a radiator of small diameter, of eliminating eddy current losses, and also of avoiding the inductance caused by any closed loops in the feeders. It is stated that these furnaces are the simplest and least expensive among the industrial electric furnaces. Additional advantages include a definite atmosphere, the possibility of operating in a vacuum, easy regulation of carburization, facility of reduction processes and the consistency of the analysis of the metal prior to and after fusion.

R. H. O.

"The chemical senses of smell and taste tell about the chemical make-up of things outside the body. Because his sense of taste is not nearly delicate enough, the research worker develops chemical and electrical means of measuring minute amounts of acidity in terms of pH values, or he uses a chemical color indicator."—T. A. Boyd, "Research."

Electric Boilers Use Jet Conduction.—(*Electrical World*, Vol. 105, No. 23.) A new type water-jet, high voltage electric boiler developed by Brown Boveri differs from all previous designs in principle and construction. Electric current is conducted through a number of water jets which radiate continuously from nozzles to the electrodes. Three electrodes are arranged concentrically about a vertical ejection pipe provided with three vertical double rows of nozzles to which water is supplied from a circulating pump. Water from the nozzles impinges tangentially on the inner surfaces of the electrodes, spreads and is deflected downward in a helical path. Tubular extensions are provided at the lower ends of the electrodes in order to concentrate the water into a jet which impinges on a perforated plate that is electrically connected to the boiler shell. Two current paths of constant length are formed per phase between the neutral point of the electrical system, to which the boiler shell and injection tube are connected, and the electrodes. One path is between the ejection tube and the electrodes, the other between the electrodes and the perforated plate. The water, along both paths, is heated by its own resistance. Under operating conditions the water is practically at evaporation temperature, since it flows continuously in a closed circuit. The greater part of the energy supplied, therefore, is used for evaporation. The boilers are built for 3 phase operation from 2000 volts upward and for outputs of 300 kw. to 10,000 kw. and above. They can be used in standby steam power plants to keep the large steam boilers warm and ready for operation.

R. H. O.

"It was while riding atop a London bus one night that Professor Kekulé saw the atoms dance about and arrange themselves into his famous 'benzene ring.'"—T. A. Boyd, "Research."

High Voltage Condenser Welding.—(*Power Plant Engineering*, Vol. XXXIX, No. 11.) The idea of producing welds by condenser discharge is not new. Attempts at this were based upon the application of condensers at low voltage, that is, the discharge current was delivered directly to the welding spot. In a recent number of *The Welding Journal* of the American Welding Society, Engineer G. I. Babat of the Research Laboratory of the Svetlana Works, U. S. S. R., describes a new method in which a condenser is charged to a high potential by a rectifier supplied from the a.c. mains. The charge stored in the condenser passes through the primary winding of a transformer under control of a special mercury vapor discharge tube, with a special igniter. This tube is capable of passing im-

pulses of short duration of the order of several hundred amperes. The secondary of the transformer consists of but a single turn and is connected to the electrodes between which the material to be welded is pressed. With the proper design of welding transformer it is possible to obtain results showing that more than 90 per cent. of the energy stored in the condenser is delivered at the welded spot. The secondary voltage of the transformer may be of the order of 20 to 100 v. This is necessary in order to deliver the required quantity of energy at the welded spot.

The principal advantages are: the quantity of energy delivered to each welded spot is controlled with an accuracy unobtainable by any other method; the welding time is subject to simple and definite regulation and it may be as short as 1/10,000 sec. so that it is possible to choose the most suitable thermal condition for any kind of material; the load on the a.c. supply is uniform and produces no violent swings in voltage.

This method of welding may be applied to line as well as spot welding. The mechanical properties and general appearance of welds produced by this method are superior to welds made by other methods of control.

R. H. O.

"One of the biggest problems in research happens to be that of supplementing the various physical senses of the investigator as aids to his powers of observation. The range of the human eye has been extended a million times by such instruments as the telescope, the microscope together with the ultra-microscope, the spectroscope, the stroboscope, the fluoroscope, and like aids to seeing where the eye alone cannot see."—T. A. Boyd, "Research."

Air Conditioning for Motor Buses.—(*Heating, Piping and Air Conditioning*, Vol. 7, No. 11.) A development by RALPH F. PEO of Houde Engineering Corp. and E. P. HECKEL of Carrier Engineering Corp. of a method for air conditioning self-propelled motor vehicles was announced at a recent meeting of the National Association of Motor Bus Operators. The System utilizes a low pressure compressor similar to a rotary type, driven by the bus engine and charged with about a gallon of "Carrene," an evaporator within the bus, a small motor driven fan distributing air through ducts along each side or down the center of the passenger compartment. An air cooled condenser, mounted outside the passenger compartment, may be kept less than 15 in. high and streamlined to harmonize with the vehicle design. On a long haul bus, seating from 32 to 35

passengers, with good tight construction, roof insulated and properly painted, the cooling load is estimated at 60,000 B.T.U. per hour, or 5 tons of refrigeration capacity. The apparatus thus far developed indicates that a system to care for such a bus will weigh less than 600 lbs., require less than 6 hp. to operate, occupy a combined space of less than 3 cu. ft., and cost a negligible sum to operate. Odors will be dissipated and smoke diluted with outside air. Private cars with "weather control" were foretold.

R. H. O.

"The recording of facts is one of the tasks of science, one of the steps toward truth, but it is not the whole of science. There are one-story intellects, two-story intellects, three-story intellects with skylights. All fact collectors who have no aim beyond their facts are one-story men. Two-story men compare, reason, generalize, using the labors of the fact collectors as well as their own. Three-story men idealize, imagine, predict: their best illumination comes from above, through the skylight."—Oliver Wendell Holmes.

A New Vacuum Switch.—(*General Electric Review*, Vol. 38, No. 11.) A. J. KLING of the Vacuum Tube Engineering Department of the General Electric Co. describes a recently developed vacuum switch that includes many of the features of the new "all-metal" radio receiving tubes and that, for certain applications, possesses numerous advantages over switches operating in air. It is a vacuum-contact tube, constructed almost entirely of metal, that performs a single-pole double-throw switching function with a rating of 10 amp. at 250 volts a.c. or d.c. Because contacts are much less in vacuum than in air the life of the contacts is long. Since there is no oxygen or other corrosive agent present, the contacts remain very clean, allowing positive contact to be made with very light pressure. The contacts, too, are protected from dust and weather. In this vacuum-contact tube the travel of the moving contact between the two stationary contacts is only about 0.018 in. However, an almost imperceptible movement is sufficient to interrupt the rated current. Operation between contacts at speeds greater than 30 times per second is possible and the switch may be mounted and operated in any position. It may be operated by an armature or by a solenoid and is admirably adapted to use with bimetallic strips for temperature control. It will also serve well in many limit-switch applications, particularly those in which the available motion and force are limited. With contacts in vacuum, interruption of the current is very rapid.

R. H. O.

"Michael Pupin has pointed out that every cultured person is expected to have an intelligent view of literature, the fine arts, and the social sciences. But who, he asks, has ever thought of suggesting that culture demands as well an intelligent view of the primary concepts in the fundamental sciences? There would be more straight thinking about things in general, if people had such knowledge."—T. A. Boyd, "Research."

Intended Substitution of the Practical Absolute System of Electrical Units for the Existing International System.[1]—(1) In accordance with the authority and responsibility placed upon it by the General Conference of Weights and Measures in 1933, the International Committee of Weights and Measures has decided that the actual substitution of the absolute system of electrical units for the international system shall take place on January 1, 1940.

(2) In collaboration with the national physical laboratories, the Committee is actively engaged in establishing the ratios between the international units and the corresponding practical absolute units.

(3) The Committee directs attention to the fact that it is not at all necessary for any existing electrical standard to be altered or modified with a view to making its actual value conform with the new units. For the majority of engineering applications the old values of the international standards will be sufficiently close to the new for no change, even of a numerical nature, to be required. If for any special reason a higher precision is necessary, numerical corrections can always be applied.

(4) The following table gives a provisional list of the ratios of the international units to the corresponding practical absolute units, taken to the fourth decimal place. Since differences affecting the fifth decimal place exist between the standards of the international units held by the various national laboratories and also because all the laboratories which have undertaken determinations of the values of their standards in absolute measure have not yet obtained final results, the Committee does not consider it desirable for the present to seek a higher precision. At the same time it hopes that it will be possible to extend the table of these ratios with a close approximation to the fifth decimal place well before the date fixed for the actual substitution of the practical absolute system for the international system.

[1] The following information was approved for general publication by the International Committee of Weights and Measures at its meeting in October, 1935, at Sèvres, France.

TABLE.

1 Ampere	International	= 0.999 9	Ampere	Absolute
1 Coulomb	"	= 0.999 9	Coulomb	"
1 Ohm	"	= 1.000 5	Ohm	"
1 Volt	"	= 1.000 4	Volt	"
1 Henry	"	= 1.000 5	Henry	"
1 Farad	"	= 0.999 5	Farad	"
1 Weber	"	= 1.000 4	Weber	"
1 Watt	"	= 1.000 3	Watt	"
1 Joule	"	= 1.000 3	Joule	"

R.

Carbon-Dioxide Fire Protection for Turbine Generators.—The Duquesne Light Co. had determined that the damage to its generating equipment by an electrical fire shall result solely from the fire and not from the means of extinguishing it. T. E. PURCELL, General Superintendent of Power Stations, in the *Electric Journal*, Vol. 32, No. 11, discusses the investigations of the use of carbon dioxide for this purpose which led to five installations of a system for using it. The largest is on a 75,000 Kva., 11.6 Kv. generator in the James H. Reed Power station. The CO_2 installation consists of two banks of tanks. One bank consists of 24 tanks, each containing 25 lbs. of CO_2; it is arranged for discharging all 24 tanks simultaneously and continuously. The other bank consists of 12 tanks of 50 lbs. each arranged for discharging singly at predetermined intervals over a period of 26 minutes. This use of a large number of tanks opened simultaneously at the first indication of fire makes possible the introduction of large quantities of gas quickly. Once the generator chambers are filled with gas to the proper concentration, it is necessary only to supply gas to replace that lost by leakage. To do this the 50 lb. tanks are used, one after another. In addition to providing for operations of CO_2 release equipment by means of a differential-protection system, pushbuttons are provided whereby the gas can be released manually. In addition to this one pushbutton station is provided with a cable connected with the tank release equipment. While at present it appears that CO_2 is the most desirable medium to use, there is still much to be learned concerning its application and the concentration required to provide adequate protection.

R. H. O.

Combating Camelthorn in California.—Although camels in some parts of Asia can graze with apparent relish upon the spiny-stemmed leguminous weed known as camelthorn, it is rated a worthless nuisance in certain parts of southern California which it

has invaded, having entered this country chiefly in alfalfa seed from Turkestan.

However, by applying certain principles of plant physiology discovered a few years ago, the State Department of Agriculture has waged a successful war against the weed's advance. It has been discovered that some plants can "go into reverse" in carrying solutions through the vascular system—that is, absorb a liquid through the leaves and take it to the roots. Accordingly, jars filled with sodium arsenite solutions are placed at intervals in a patch of camelthorn. A handful of the growing plants is thrust into the poisonous solution and left there. The soluble arsenite is carried through the leaves and stems into the long fibrous roots. Because of the extensive root system, large areas of the weed are killed.

C.

"Modern meteorology is said to have originated from an observation made by Benjamin Franklin as a result of his personal correspondence with friends in Boston. He noticed that, quite contrary to the accepted opinion of the time, storms traveled in the opposite direction to the wind, or that northeasters sometimes reached Philadelphia before they did Boston."—T. A. Boyd, "Research."

A New Ingot Heating Furnace.—(*Iron Age*, Vol. 136, No. 21.) The original conception of the so-called soaking pit, involved in all processes of steel making, was an insulated chamber into which steel ingots were charged soon after stripping the pouring moulds. This chamber allowed the cooling process to continue until the molten interior of the ingot had solidified and until the entire ingot had arrived at a uniform temperature suitable for rolling. Later, in order to speed up production, these pits were heated; fired by the Siemens regenerative principle and recently by a method which replaced the regenerators by continuous recuperators. A new furnace, called an ingot heating furnace, has now been designed by the Salem Eng. Co., Salem, Ohio. It incorporates all the developments which have been made in other high temperature equipment, including insulation, sealing means for control of atmosphere, premixing of fuel, proportioning control of fuel and air, automatic temperature control, and uniformity of temperature. Such a furnace has been in continuous operation at the Campbell Works of the Youngstown Sheet and Tube Co. for six months. The furnace is enclosed in a circular shell, lined with special quality firebrick which is backed up with 5 in. of insulating brick. The cover seals in a sand trough. The pit is fired by means of gas burners, arranged

to utilize gas of approximately 500 B.T.U. per cu. ft. This is made up of a mixture of blast furnace, coke oven and natural gases. The burners fire tangentially through the wall at the bottom of the pit, where the wall is greater in diameter than it is at the top. Products of combustion are vented through a port in the center of the bottom of the furnace.

R. H. O.

Sun's Rays Used for Refrigeration.—C. F. GREEVES-CARPENTER. (*Refrigerating Engineering*, Vol. 30, No. 6.) That the powerful light rays from the sun could ever be practically used for the purpose of creating refrigeration may appear fantastic, though the principle involved is quite simple. An actual cooling unit, however, has been devised by Otto H. Mohr of Concord, Calif., who discovered that he could create temperatures ranging lower than 20° F. using an absorption cycle. The complete unit consists of a solar absorber, a generator, condenser and receiver. The solar absorber is a sphere of special crystal-clear glass, made by the inventor, which permits the penetration of ultra-violet rays. It is capable of withstanding two extremes of temperature. In operation, the sphere is cool on the side exposed to the sun and hot on the lower side. The inside of the sphere is filled with clear, dehydrated oil, specially treated. The sphere is fitted into a special plate glass valve and its lower edge rests about 8 in. above the absorber or heating unit which in turn rests slightly above the bottom of a thoroughly insulated box. In the center of the absorber are two pipes, one telescoped inside the other. The inner pipe contains a pint of highly dehydrated oil of 400° flash, the same as that which is in the sphere, except that the latter is of a somewhat lower flash point. The oil acts as a conductor for the heat in the unit and the heat is conducted up to the boiler. As the heat is absorbed in the generator, cooled oil is returned by a circulatory system to the absorber. It is then automatically reheated and the process is continued. Refrigerant vaporized in the generator, passes through a condenser in which it is liquefied and is then passed to a cooling unit or receiver. Here it is again vaporized and the cool liquid is passed back to the generator. Neither strong rays from the sun nor a warm day are necessary for satisfactory operation of the unit, as it involves only light, not heat waves.

R. H. O.

Benzene in Natural Gas.—(U. S. Bureau of Mines Report of Investigation 3293.) A colorimetric method for the determination of benzene in amounts as low as 0.001 mg. has been developed re-

cently by H. H. SCHRENK, W. P. YANT AND S. J. PEARCE at the U. S. Bureau of Mines Pittsburgh Experiment Station. The method involves the direct nitration of either liquid- or gas-phase benzene, followed by neutralization, extraction with butanone, and final treatment with sodium hydroxide which produces a violet color.

The primary objective of this work was to develop a procedure that would be suitable for hygienic investigations. During a further study of possible interference by chemicals that might be present in those situations in which the method would be employed, it was found that a specimen of hexane prepared by fractionation of West Virginia natural gas gave a positive result for benzene. Since no traces of benzene could be detected in other synthetically prepared paraffins, it was apparent that benzene occurred naturally in at least one specimen of natural gas. Additional tests showed that about 2.95 p.p.m. by volume of benzene vapor was present in the natural gas supplied to the Pittsburgh Experiment Station while almost 18.0 p.p.m. was found in a "wet" natural gas taken directly from a private well near Pittsburgh. This finding of benzene in natural gas and natural-gas condensates is of interest from the viewpoint of the origin and subsequent thermal environment of natural gas and petroleum.

C.

"He did not know that the very worst way of getting hold of ideas is to go hunting expressly after them. The way to get them is to study something of which one is fond, and to note down whatever crosses one's mind in reference to it, either during study or relaxation, in a little notebook kept always in the waistcoat pocket."—Samuel Butler.

Nuts.—According to the U. S. Department of Agriculture there is no dearth of nuts—at least not those of vegetable origin. The total production of English walnuts, pecans, almonds, and filberts is about 39 per cent. greater than last year.

Nuts are concentrated food. They contain little moisture and much fat, protein, and carbohydrates. Nuts should not be eaten to take the place of meat and other animal proteins. According to the Bureau of Home Economics, to get enough nut protein at a meal it would be necessary to eat too much fat along with it.

The fat content of such common nuts as almonds, Brazil nuts, cashew nuts, filberts, hickory nuts, peanuts, pecans and walnuts may vary between 45 and 70 per cent. The protein will range from 10 to 25 per cent. and the carbohydrate from 7 to 25 per cent. The

proportion of mineral matter is small, but most nuts, if unblanched, are good sources of iron. Nuts are high in phosphorus and vitamin B, low in calcium and vitamin A.

C.

"Charles F. Kettering has suggested that a manufacturer ought to spend on research as much as he spends on advertising."—T. A. Boyd, "Research."

THE FRANKLIN INSTITUTE

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Wonderland of Science NOTES

JANUARY, 1936

EXPLAINS ELECTRONS, DEMONSTRATES USES.

ELLIS L. MANNING, Physicist,
Christmas Week Lecturer at
The Franklin Institute.

What electrons do and the uses to which they have been put in engineering and industrial problems were demonstrated by Ellis L. Manning, physicist, of the General Electric Research Laboratory at Schenectady, New York, during the Christmas Week Lectures for Young People given at The Franklin Institute, December 26, 27, 28.

The lectures, made possible by the James Mapes Dodge Lecture Foundation, were entitled "The New Country of the Real Lilliputians."

Mr. Manning, a member of the American Physical Society and an associate member of the American Institute of Electrical Engineers, has spent years of research in electronics and has had experience as a teacher and demonstrator and as a result he presented an accurate and extremely interesting account of recent work in this field.

THIRTY-SECOND ANNIVERSARY WRIGHT BROTHERS' FLIGHT CELEBRATED IN HALL OF AVIATION.

To commemorate the 32d anniversary of the flight made by the Wright Brothers at Kitty Hawk, December 7, 1903, students from the Aviation Department of the Camden County Vocational School, Merchantville, New Jersey, made a pilgrimage to the Hall of Aviation of The Franklin Institute. They were headed by their instructor, Arthur E. Arrowsmith,

and B. I. Carson, Mathematic Instructor. C. Townsend Ludington, Associate Director in charge of the Aviation Section, and Ralph McClarren, aeronautical engineer, received the visitors.

The program included a short address on "aviation progress" by Mr. McClarren and an inspection of the historic Wright plane which was rebuilt by the boys in the Aviation Department of the vocational school and flown December 7, 1934, at the Central Airport in Camden, by Marshall Earl Reid.

The Wright plane on exhibition at The Franklin Institute is known as the Wright Brothers' Airplane No. 13. It was given to the Institute by Grover Cleveland Bergdoll.

Director Henry Butler Allen sent the following message to Dr. Orville Wright at Dayton, Ohio.

"The Franklin Institute joins with you in observing the 32d anniversary of your epoch-making flight at Kitty Hawk. The Institute is proud of the opportunity which it has through its Hall of Aviation of paying tribute to you and the new science to which you gave wings."

LECTURE-RECITALS ON THE ORIGIN AND HISTORY OF MUSIC FOR THE GENERAL PUBLIC.

BY

GUY MARRINER,

Associate Director in charge of the Music Section.

No. 7, January 12th:

Monteverde. Opera, oratorio, Lully, Purcell.
Violin makers and players.
Chamber music. The Scarlattis.
Lully, Purcell, Arne, Shield, Scarlatti, Rameau.

No. 8, January 26th:

Bach, Handel, Gluck.
France and Italy in Eighteenth century.
Bach, Handel, Gluck.

These are two of a series of sixteen lecture-recitals to be given on the second and fourth Sundays of each month. The series continues through May, 1936.

Visitors to the "Wonderland of Science" may attend these lecture-recitals without additional charge.

SPECIAL EXHIBITIONS

In Hall of Graphic Arts, Second Floor.

Exhibitions of Prints by the School Children of Philadelphia, Grammar and High School Grades, January 4th to 19th inclusive.

"Travel in Print," Second Annual International Exhibition of Travel Advertising. More than 18 countries represented. January 23d to February 23d inclusive.

FELS PLANETARIUM.

"Evening Skies of Winter."

(Lasting about 45 minutes.)

This lecture will be given during the month of January.

Times: 3 o'clock and 8:30 o'clock every afternoon and evening (except Mondays and Tuesdays).

Saturdays: 12 M., 3, 4, and 8:30 P.M.

Sundays and New Year's Day 3, 4, 8:30 P.M.

Evening visitors to the planetarium may visit the observatory without extra charge.

ADMISSION 25 CENTS PER PERSON.

SPECIAL LECTURES WITH DEMONSTRATIONS—MOVIES IN THE "WONDERLAND OF SCIENCE."

Open afternoons and evenings (except Mondays and Tuesdays).

All the sections will be closed on Monday and Tuesday of each week in order to give our scientific staff sufficient time to arrange special demonstrations and to adjust all operable exhibits.

Hours: 2 P.M. to 10 P.M. except Saturdays.
10 A.M. to 10 P.M. Saturdays.

2:30 P.M.	Making Giant Telescope Lens	Astronomy	2d Mez.
2:30 P.M.*	The Making of Perfume	Chemistry	1st Fl.
2:30 P.M.*	Wireless of Yesterday and Today	Elec. Com.	1st Fl.
3:00 P.M.	Things that Spin	Physics	2d Fl.
3:00 P.M.*	Autogiro Invades America	Aviation	1st Fl.
3:30 P.M.	Wireless of Yesterday and Today	Elec. Com.	1st Fl.

4:00 P.M.	The Making of Perfume	Chemistry	1st Fl.
4:00 P.M.	Lecture-Recital (January 12th and 26th) By Guy Marriner	Lec. Hall	Gr. Fl.
4:15 P.M.*	Making Giant Telescope Lens	Astronomy	2d Mez.
4:30 P.M.	Autogiro Invades America	Aviation	1st Fl.
5:00 P.M.*	Things that Spin	Physics	2d Fl.
7:45 P.M.	The Making of Perfume (FRIDAYS ONLY)	Chemistry	1st Fl.
	Special Exhibits	Graphic Arts	Gr., 1st, 2d Fls.

* Saturdays and Sundays only.

January 1, 1936 (New Year's Day)
open 10 A.M. to 10 P.M.
Special showings in all sections.

LIBRARY HOURS

Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, 9 A.M. to 5 P.M.
Closed Sundays and Holidays.
Open from 7 P.M. to 9 P.M. on evenings of Institute lectures.

OFFICE HOURS

Monday, Tuesday, Wednesday, Thursday, Friday, 9 A.M. to 5 P.M.
Saturdays 9 A.M. to 12 noon. Closed Sundays.

Entrance to offices and library on Parkway side of the building.

Entire building closed July 4th and Christmas Day.

BELGIAN MEMORIAL STAMPS.

The recent issue of Belgian Memorial Stamps in honor of the late Queen Astrid, of Belgium, has been given to the Franklin Institute by James S. Rogers, Esq.

It has been placed in the Hall of Graphic Arts of the Institute, on the second floor.

RECENT ACQUISITIONS IN THE "WONDERLAND OF SCIENCE."

Photo-electric Shotgun. Loaned by General Electric Research Laboratory.
Sword and Glass Tube used by Benjamin Franklin.
Specimen of Heavy Water. Donated by Dr. Harold C. Urey.
Coils and Glass used by Michael Faraday. Donated by the Royal Institution of Great Britain.

"Photona"—a pipeless photo-electric organ. Loaned by WCAU Broadcasting Company.

Model of "DeWitt Clinton" Engine and Train. Loaned by Mr. Adam Ehling.

Ford Automobile—Model 1910, Touring. Donated by Mr. Milton Fritsche.

"EVERY MEMBER ENROLL A MEMBER."

With the slogan, "Every Member Enroll a Member," the membership campaign committee, headed by W. Chattin Wetherill, Vice-President of The Franklin Institute, urges every member to participate in the campaign for 10,000 new members.

"If everyone who now enjoys the benefits of the Institute would secure just one new member, the campaign would move more quickly along the road to success," states Mr. Wetherill who announces that early tabulations indicate that there is an enthusiastic response to the welcome, "The Doors Of The Franklin Institute Are Opened Wide For You."

The campaign, temporarily halted at Christmas, continues with redoubled effort on the part of over 800 active men and women workers.

"If you are not already on a team you can constitute yourself a committee of one to bring in new members. Information and membership blanks will be supplied to you by calling or writing the campaign headquarters in the Institute.

INCREASED ATTENDANCE.

The increase in attendance in both the "Wonderland of Science" and the Fels Planetarium over that of last year attests a growing appreciation of the educational facilities offered. Groups of educators, business and professional men and women are coming from distant points as well as metropolitan Philadelphia to see and hear the wonders of science explained and demonstrated.

The special demonstrations with talks and movies are very popular. Attendance at them is ever on the increase.

Another encouraging fact is that clubs, associations, groups and organizations are visiting the Institute in a body. They are including the Institute in their regular educational program.

Members are availing themselves more and more of the privileges of membership.

The coming year promises to break all attendance records and you and your families and friends are invited to make 1936 an "all high" in attendance.

CHRISTMAS PLANETARIUM DEMONSTRATION PRAISED BY PULPIT AND PRESS.

Acclaimed by pulpit and press, "The Heavens Declare," a dramatic planetarium presentation of the First Christmas, attracted thousands of men, women and children to the Fels Planetarium during its showing from December 11 through December 28. Public response to its appeal made additional showings a daily necessity and prompted an extension of its schedule from December 24 to December 28.

The demonstration was under the direction of James Stokley, Associate Director in charge of the Astronomical Section, and his staff, and Guy Marriner, Associate Director in charge of the Music Section.

Plans are already being made for a special planetarium demonstration at Easter time.

MAGIC CHRISTMAS TREE ATTRACTS THOUSANDS.

Young and old were delighted with The Magic Christmas Tree which, on display in the Lecture Hall, mystified and intrigued the crowds that viewed it, during the Holiday Season.

The 14 foot tree had been treated with chemicals which when illuminated by invisible light, called ultraviolet radiation, gave off all colors of the spectrum. The ornaments, icicles, balls, stars, toys, tinsel, etc., had likewise been painted as was a stratosphere balloon ornament suspended from the ceiling above the tree. Some of the articles of decoration had been treated with chemicals that caused them to give off colored lights in the dark.

Dr. James Barnes, under whose direction the tree was prepared, acknowledges with thanks the coöperation of Gimbel Brothers, The Kimball Glass Company, Pineland, N. J., and Mr. Frank Hartmann.

GIFT IN HONOR OF DR. McCLENAHAN.

In tribute to the late Dr. Howard McClenahan, Secretary of The Franklin Institute, an anonymous donor presented a Steinway piano to the Music Section of the Institute. An appropriate engraved plate will be placed on the piano, it was announced by Guy Marriner, Associate Director in charge of the Music Section.

WATT BI-CENTENARY CELEBRATION.

The Franklin Institute will take an important part in the three-day celebration of the 200th anniversary of the birth of James Watt on January 19, 20 and 21, 1936. It joins Lehigh University, The American Society of Mechanical Engineers and The Newcomen Society of England in a three days' commemoration.

On Sunday, January 19, there will be a special display and the demonstration of models of the steam engines of Watt and Newcomen and other exhibits appropriate to the occasion at The Franklin Institute. The public is invited to attend.

On Monday, January 20, representatives of the Institute will attend the exercises at Lehigh University.

On Tuesday, January 21, the Institute will welcome members of the Newcomen Society which will hold its meeting in the Lecture Hall in the afternoon. Later the Institute will hold, under its auspices, a formal banquet in the Palm Garden Room of the Bellevue Stratford Hotel, Philadelphia.

Members of the Institute, their families and their friends are invited to attend the Sunday afternoon program and the banquet, Tuesday night. Reservations for the banquet, at $3.50 per plate, can now be made with the office of the Director of The Franklin Institute.

The Advisory Committee for The Franklin Institute is: Nathan Hayward, chairman, Henry Butler Allen, Hon. George Wharton Pepper, A. Atwater Kent, W. Chattin Wetherill and Samuel M. Vauclain. Those on the Dinner Committee are: W. H. Fulwiler, M. M. Price and N. E. Funk.

RADIO BROADCASTS FROM LECTURE HALL OF INSTITUTE.

Radio broadcasts, in dialogue form, are made through the courtesy of Station WCAU, every Saturday evening at six o'clock. These broadcasts come from the Lecture Hall of the Institute and attendance at them is free to visitors to the "Wonderland of Science."

December's schedule is typical of the standing of the speakers and the nature of their subjects, viz.

Rev. J. J. Lynch, S.J., Fordham University.—"Earthquakes."

Mr. Horace Gardner, J. B. Lippincott & Co.—"The Science of Book Publishing."

Mr. Henry Butler Allen, Director, The Franklin Institute.—"Science and the People."

Major Thomas Coulson, Member of the Department of Public Relations, The Franklin Institute.—"Scientific Wonders of 1935."

For January broadcasts see your daily newspapers.

MODEL AIRPLANE BUILDERS GIVEN AWARDS.

Presentation of medals to winners of the scale model contest, sponsored by the Philadelphia Model Airplane Association and The Franklin Institute, were made, Friday, December 13, in the Lecture Hall.

Final arrangements for the contest had been made by C. Townsend Ludington, Associate Director in charge of the Aviation Section, and C. H. English, head of the Playground Association.

The Contest Committee was composed of C. Townsend Ludington, Percy Pierce, Victor R. Fitz and Ralph H. McClarren.

Beginning the first of the year another scale model contest will be conducted under the joint auspices of The Franklin Institute and the Philadelphia Model Airplane Association.